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M I N U T E S   A N D   P R O C E E D I N G S

of the nineteenth meeting of the

ARMY - NAVY - NRC VISION COMMITTEE

May 27-28, 1947

Washington, D.C.

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Minutes of the Nineteenth Meeting

May 27-28, 1947

Washington, D. C.

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Dr. Donald G. Marquis
Dr. H. Richard Blackwell

Tuesday, May 27, 1947

1. The Chairman called for corrections or alternations in the Minutes and Proceedings of the Eighteenth Meeting. There were no corrections.

2. Report of the Subcommittee on Legibility:
Walter F. Grether- 13

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The Chairman announces the formation of a Subcommittee on Atmospheric Optics. Members are: Dr. E. O. Hulburt, Chairman; Mr. F. C. Breckenridge; Dr. Howard S. Coleman; Mr. C. A. Douglas; Dr. S. Q. Duntley; Mr. L. P. Harrison; Dr. Hans Neuberger.

A meeting was held on Tursday, March 27, in Washington, D.C., to discuss proposals for field tests of visibility to be conducted jointly by the Optical Inspection Laboratory, Pennsylvania State College, and the Vision Research Laboratory, University of Michigan. The following resolution was unanimously approved by the Subcommittee:

"It is the sense of the subcommittee that it is desirable to carry out a research program to determine means by which laboratory vision data can be used to predict the range at which objects, luminous and nonluminous, are visually detectable both with and without visual aids. This program might well include: (a)the investigation of reduction of contrasts and of illumination by the atmosphere; and (b) the determination of conversion factors by which laboratory data can be adjusted into useful field values."

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REPORT BY SUBCOMMITTEE OF THE ARMY-NAVY-NRC VISION COMMITTEE ON STANDARDS TO BE EMPLOYED IN RESEARCH ON VISUAL DISPLAYS

At the request of the Executive Secretary of the Army-Navy-NRC Vision Committee, a subcommittee was formed to discuss possible standardization of research on the effectiveness of visual displays. A meeting of this subcommittee was held in Ann Arbor, Michigan, on 4 and 5 April 1947 and was attended by the following: D. G. Marquis, Executive Secretary, Army-Navy-NRC Vision Committee, H. R. Blackwell, Technical Aide, Vision Committee, John L. Kennedy, Leonard C. Mead, Clifford P. Seitz, John R. Bromer, Alexander C. Williams, Jr., and Walter F. Grether (substituting for Paul M. Fitts). By action of the group. W. F. Grether was elected to serve as Chairman. This report presents the recommendations agreed upon by this subcommittee concerning standardization in the research field under discussion.

I. Statement of Area of Interest.

The area of interest of the subcommittee is "Standards to be Employed in Research on Visual Displays." Any method of transmitting information to the human being through the visual sense is considered to be a visual display. This research area is further defined by a classification of research into three major psychological categories as follows:

1. Discrimination. This category is similar to what is normally called "acuity," but is broader and includes all work at the sensory discrimination level. No meaning or recognition of familiar patterns need be involved.

2. Recognition. This is similar to, but broader than, the area normally called "legibility," and involves the recognition and identification of familiar patterns which may be words, numbers, symbols, or any type of pattern. Meaning or understanding need not be involved.

3. Interpretation. This covers research at the highest behavioral level, and involves meaning and understanding as shown by action appropriate to the information provided in the visual display. Such action may be verbalization of the displayed information or manipulation of control levers and switches. Interpretation may involve discrete reactions or continous pursuit-type motor adjustments.

II. Purpose to be Achieved.

In order to obtain comparability of visual display research data from different laboratories, and thereby to increase the efficiency and value of research in this area, it is desirable that some standardization be introduced with regard to subject groups, units of measurement, fixed values of stimuli not under investigation, and methods of experimental measurement. It was agreed that the standards recommended by this subcommittee should be circulated for comment and later published so as to be available to workers in this field. These recommendations are considered as tentative and subject to considerable revision before they become an established guide to research workers.

It should probably be stated that it was not the purpose of the subcommittee to specify standards or stimulus characteristics which result in optimum visual displays. Such specification must await the results of current and future research. Likewise, the subcommittee was not concerned with standards for the design of experiments or the quality of experimental work. Particular consideration was given to the avoidance of standards which would unduly hamper or stereotype research efforts.

III. Selection of Subjects and Control of the Subject Variable.

The visual and intellectual capacities of the subjects are important variables in research on the effectiveness of visual displays. Comparability of results from different studies is therefore limited by the comparability of the subject groups. Recommendations regarding standardization of the subject variables are as follows:

1. Visual acuity. All subjects should have visual acuity of 20/20 or better, for both near and far vision, for both eyes, as measured under standard conditions recommended by the Vision Committee to the Surgeon General,[1] or by means of recently developed commercially available tests such as the Bausch and Lomb Ortho-Rater or American Optical Company Sight Screener. If the visual standard is met with optical correction, such correction must be worn by the subject during all experimental testing.

2. Color vision. In research involving color differences in the display all subjects should have normal color vision as indicated by a perfect score on any of the commonly used pseudo-isochromatic charts.

3. Intellectual capacity. Standardization of the distribution of relevant intellectual capacities in the subject group is considered desirable if comparability is to be obtained in the results of different investigations. This, however, is not considered to be economically possible until the most relevant tests of intellectual capacities have been determined. In lieu of specific standards, therefore, it is recommended that research workers report as complete a description as possible of the subject group with respect to education, intelligence, work experience, sex, age, and perceptual, verbal, numerical and motor abilities. It is further recommended that whenever possible such data on the subjects be correlated with the experimental variables being investigated as an aid to future efforts toward standardization. Where accurate equating of subject groups is required it is suggested that a sample of the actual experimental materials will provide the most valid test on which to match the subjects.

IV. Units of Measurement.

The following are recommended as units of measurement for specifying the indicated stimulus variables:

1. Distance: feet and inches (English System)

2. Size: visual angle in degrees, minutes and seconds of arc, or actual dimensions in English System (provided distance is also given). In the case of standard printed material the point (approximately .0138 in.) is recommended as the unit.

[1] Testing Visual Acuity, Manual of Instructions. Prepared by the Subcommittee of Procedures and Standards for Visual Examinations of the Army-Navy-NRC Vision Committee. Copies can be obtained from the Vision Committee.

3. Brightness: foot lamberts.

4. Illumination: foot candles.

5. Time: hours, minutes and seconds.

6. Color or hue: modal wave-length in millimicrons if possible; otherwise, by matching Munsel scale number.

7. Saturation: wavel-length distribution in millimicrons if possible; otherwise, by matching Munsel scale number.

V. Values for Non-Experimental Variables.

In any experiment on effectiveness of visual displays only a limited number of stimulus variables will be under investigation. In order to obtain comparability between experiments it is desirable that such non-experimental variables be set at standard values. The following standard values are recommended:

1. Distance. The stimulus material should be placed at one of the three following distances from the eye:

a. 14 inches, to represent normal reading distance.

b. 28 inches, to represent instrument viewing distance in aircraft.

c. 20 feet, to represent distance for far acuity measurements.

2. Size. For printed materials 10 point type is recommended. For instrumental type displays standards are shown in Figure 1. It will be noted that dimensions are given for minor, intermediate, and major graduations, numerals and letters. The experimenter may not choose to use all of these on the particular dials which he is studying, and should select those which seem most appropriate. Normally the largest graduation marks should conform to the major dimensions in Figure 1. If only one other size of graduation marks is used, the intermediate dimensions would be preferred. The major letter size should probably never be used in complete words, but only in single letter abbreviations (as for example N, E. S. & W on a compass dial). The pointer length should be such that the tip reaches the inner end of the shortest graduation marks. The pointer length will, therefore, differ from that shown if no minor graduations are used, or if some other overall dial diameter is used.

3. Style. For printed materials it is recommended that any common modern or ultra-modern type face in capitals and lower case (as opposed to all caps) be used. Printing produced by typewriter is not recommended. For margins, line length and spacing it is suggested that recommendations of Paterson and Tinker,[2] page 156 and 157, be followed. For instrumental type displays the style shown in the Army-Navy Aeronautical Design Standard No. AND10400 is preferred. Since most research workers will have no means of accurately reproducing this style, the very similar capital letters of either Wrico or Le Roy lettering guides are suitable as alternatives.

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[2] Paterson, Donald G., & Tinker, Miles A. How to make type readable. Harper & Bros., N. Y. 1940, 1-209

4. Brightness. It is recommended that the MacBeth Illuminometer, or comparable photometric instrument, be used for measuring brightness, and that the white area, whether figure or ground, have a brightness as follows:[3]

a. 30 foot lamberts, as representative of daylight reading conditions.

b. 0.1 foot lamberts, as representative of night lighting on instruments.

5. Color of figure and ground. Black figures on a white background are recommended for general use. Where primary application of results is to be to aircraft instruments which are designed for night lighting, white figures on a black background are to be preferred.

6. Contrast. Maximum possible contrast is recommended unless inappropriate to problem. Where contrast is other than standard black on white or vice versa, it should be stated as the brightness difference over the greater of the two brightnesses (DI/I where I is the greater of the two brightnesses).

7. Adaptation level. Sufficient time should be allowed for adaptation of the eyes to the brightness level under which the test is being carried out (for appropriate data see Hecht, Haig, and Chase,[4] page 838).

8. Exposure time. An exposure time of 0.1 sec. is recommended for use when single visual fixations are desired. In all other cases it is believed that exposure time, if limited, must be adjusted to the item difficulty and the purposes of the experiment.

VI. Experimental Techniques.

There is, at present, a great diversity in the experimental techniques used in research on visual displays. This not only requires that each experimenter report a detailed description of his apparatus and testing procedure, but makes valid comparisons between experiments virtually impossible. The use of a small number of proven measuring techniques would aid greatly in systamatizing the data on effectiveness of visual displays. Although it is agreed that such standardization of techniques would be desirable, there are, at present, insufficient data about the possible methods to justify a choice among them. Experimenters in this field are, therefore, encouraged to carry out methodological studies, and also to present all data which might aid in evaluating their experimental techniques. It is hoped that in the future some standardization of experimental techniques can be achieved in this field.

As a step toward eventual standardization, a tentative classification of available techniques is presented. Such systematization should clarify thinking about experimental techniques and aid research workers in designing

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3 For measuring brightness of very small areas, such as white numerals on a black ground, two procedures are suggested: (1) That the area be magnified by means of a convex lens, and an empirically determined correction factor introduced; (2) That the brightness be measured, under the same illumination, of a larger test area which duplicates the reflecting (and fluorescing properties) of the smaller area.

4 Hecht, S., Haig, C., & Chase, A. M. The influence of light adaptation on subsequent dark adaptation of the eye. J. Gen. Physiol., 1937, 20, 831-850.

their experiments. One method of classification is in terms of the control of the speed and accuracy variables. Another method is in terms of the nature of the subject's response. These two tentative methods of classification are outlined below.

1. Types of research techniques according to control of speed and accuracy variables.

a. Achievement of correct response required before presentation of next trial. Speed is the primary measure, although wrong responses may also be tabulated.

b. Controlled exposure time for each test item. Accuracy is the primary measure, although other data such as reaction time or eye movements may also be recorded.

c. Controlled rate of continuously changing task (such as a pursuit test). Accuracy is the primary measure.

d. Controlled total time for group of test items. Both accuracy and speed are measured, speed being computed from the number of items completed. In this method control of time serves primarily as a motivating influence.

e. No control of time or errors. Both accuracy and speed are recorded.

2. Types of research techniques according to response required of subject.

a. Verbal response (written or oral).

(1) Simple choice (such as yes or no; right or left: higher, same, or lower).

(2) Complex choice (may be one or more words or digits out of a large possible number).

b. All-or-none motor response (such as operation of one or more keys, switches or levers).

c. Graded and directional motor response (as required in a pursuit test).

The above classifications are to be considered as very broad and tentative, and are presented with the hope that they will aid and stimulate thinking about experimental techniques for research on visual displays.

For the Sub-Committee
Walter F. Grether, Chairman

Discussion

Dr. Hecht remarked that the specification of contrast as $\Delta I/I$, where I is the greater of the two brightnesses, whether black numerals on white or white on black, runs counter to the accepted usage of the symbols. After considerable discussion it was generally agreed that the two brightnesses used should be specified and that the computation of contrast be left to the reader.

DIMENSION		MINOR	INTERMEDIATE	MAJOR
Graduations	Width	0.015 in.	0.020 in.	0.025 in.
	Length	3/32 "	5/32 "	7/32 "
Numerals and Letters	Heigth	3/32 "	1/8 "	3/16 "
	Stroke Width	0.015 "	0.020 "	0.025 "

Figure 1. Recommended standard dimensions for instrumental displays suitable for night lighting and 28-inch viewing distance.

ABSTRACT OF DR. DOROTHY NICKERSON'S

REPORT ON THE FUNCTIONS OF THE INTER-SOCIETY COLOR COUNCIL

Dr. Nickerson outlined the history of the Inter-Society Color Council, whose formation arose from the need for a "horizontal" organization cutting across the many societies concerned in various ways with color and color vision. She discussed past chairmen of the Council and some of the more dramatic activities of the organization. She reported that, at the present time the I.S.C.C. has 13 member bodies, which are scientific societies, and in addition, individual members representing interests not organizing into societies.

Dr. Nickerson reported that the function of the Council is to standardize terminology, and to aid the application of scientific data to science, art, and industry. These aims were achieved through meetings of the Council, technical discussion, and business, and through general clearing house activities of the Secretary of the Council (Dr. Nickerson).

Several bulletins were furnished by Dr. Nickerson describing in more detail the Council's organization. In addition a typical news letter was furnished, through which new facts and applications are circulated to the members. The bulletins and news letter are in the files of the Vision Committee and can be loaned upon request.

BRIGHTNESS, VISUAL ACUITY, AND COLORBLINDNESS

By

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The shape and location of the spectrum luminosity curves of colorblind individuals have by now been determined with good precision. Fig. 1 presents the average measurements of six deuteranopes and six protanopes, as found by Pitt. As usual, the curves are drawn by placing the point of maximum brightness for each at 100 per cent.

The question arises as to whether the three curves really have the same height, and if not, what their relative heights are. To answer this question we measured the visual thresholds of colorblinds and normals in different parts of the spectrum. We used 9 color normals, 6 protanopes, and 7 deuteranopes, all men between 20 and 35 years of age.

All subjects were tested for their color vision several ways. The first test consisted in reading the Ishihara pseudoisochromatic plates, "Tests for Colorblindness", fifth edition. Following this, the subject read Stilling's "Pseudo Iso-Chromatische Tafeln", 19th edition. Anyone who read correctly all the plates in these two tests without hesitation was tentatively considered normal. He was then further tested for the Rayleigh equation with an anomaloscope made in our own Laboratory. The equation requires the subject to match a yellow of 575 mμ with a mixture of 555 mμ green and 635 mμ red. A subject was considered normal only when his match was sharp and fell in the narrow range found by us in unpublished studies with many normal persons.

The colorblind subjects were all complete dichromats. We first chose those persons who made extensive errors in the Ishihara and Stilling tests. Of these we selected only those who in the anomaloscope test were able to match perfectly the yellow of 575 mμ with the green of 555 mμ by itself, and also with the red of 635 mμ by itself. By comparing the relative brightness at match of the yellow and red we classified the subject as protanope or deuteranope; if the red was much brighter (to us) than the yellow he was called protanope, whereas if at match the red and yellow were equally bright, he was called a deuteranope. The final critical test was always to determine the presence of a neutral point, or white spot, in the spectrum. Only those subjects who matched a sharply located neutral point in the spectrum with whole white light of 5000°K as a standard were considered as complete dichromats, and were used as subjects for the measurements. The neutral point determination were made with a modified Helmholtz Color Mixer.

II

The measurements of the foveal thresholds were made with the original Hecht-Shlaer adaptometer. In this instrument the intensity of the test light is varied with neutral filters and a neutral wedge, while the color of the

light is controlled by appropriate color filters.

Five regions of the spectrum were isolated by means of Corning and Wratten filter combinations. Observations were monocular, and the subject fixated a tiny red point reduced to the lowest possible brightness by the subject himself. The circular test field was central, and was one degree in diameter. Exposures were in flashes of 1/5 second, and were controlled by the subject himself. The experimenter arranged the wedge and the filters and the subject manipulated the shutter when he was ready to observe the flash. He merely reported the presence or absence of light.

The natural pupil was used. Because the subjects were all dark adapted, the pupil was maximal. Variations in the pupil size at maximal pupil opening are of only trifling influence on cone vision because of the Stiles-Crawford effect. We allowed our subjects at least 15 minutes in the dark after a preliminary stay in the laboratory before beginning observations, so that cone dark adaptation was complete.

An experimental session consisted of determining three times in succession the final threshold for seeing the central 1° field at the five selected positions of the spectrum. We always started with the blue end of the spectrum and worked toward the red. Most of our subjects came for four such sessions.

III

Our interest in the present study is to determine the differences in foveal threshold between colorblinds and normals. To establish the normal base-line, we have averaged the measurements for the nine color normals at each spectrum locus, and have put the average threshold value equal to unity. The average logarithmic differences between the normals and the two types of colorblindness are shown in Fig. 2. It is apparent that beginning with the blue and going toward the red, the threshold of the protanope, compared to the normal, steadily rises in the spectrum. The two thresholds are practically identical in the blue, but the protanope threshold is well over 1 log unit greater than the normal in the red. The deuteranope threshold is also very nearly normal in the blue; but it definitely rises in the green and remains at about that level through the rest of the spectrum.

In order to see what these measurements actually do to the shapes and positions of the colorblind luminosity curves, we need to place them in relation to the normal luminosity distribution in the spectrum. This is done in Fig. 3 with relation to the color normal curve taken from Wald's recent study. The reason for choosing Wald's data is that they were secured in essentially the same way as ours, that is, by measurements of the energy threshold of a 1° field in the central fovea after complete dark adaptation. However, with only minor differences the curve is practically the same as the standard luminosity curve for the normal eye which has been used for years.

Fig. 3 shows unequivocally that for both types of colorblindness there occurs not merely a shift of maximum and a change in shape of the curve, but a real loss of luminoisity in the spectrum.

To determine the precise amount of this loss, we have plotted the data in arithmetical form in Fig. 4. The area under such an arithmetical luminosity curve represents the total brightness of an equal energy spectrum. If the

area under the normal curve is put equal to 100, the area under the protanope curve turns out to be 51.0, whereas the area under the deuteranope is 61.2. Evidentally, compared to the normal, the protanope loses almost one-half the luminosity of the spectrum while the deuteranope loses almost two-fifths the luminosity of the spectrum.

IV

These losses in luminosity are large. In order to confirm their existence we studied their influence on visual acuity. Fig. 5 shows the normal classical relation between visual acuity and brightness for direct cone vision. If dichromats have lost luminosity in their cone vision a given amount of white light should appear less bright to their eyes than to normal eyes. Therefore to see the same brightness and to perform the same functions, the dichromat's eyes should need more light than the normal person's. It is as if the acuity-brightness relation were merely displaced on the horizontal axis toward higher brightnesses; and such displaced curves are shown in Fig. 5.

To test these ideas we set a given visual acuity task and determined the brightness (to normal eyes, of course) required for its resolution by normal and colorblind eyes. The test object was a black Landolt ring whose gap subtends 3.5 minutes at 2 meters. It was seen against a large white background illuminated by light of 5000°K, produced by an automobile headlight lamp and Corning filter 590. The broken ring was exposed from behind a white shutter for 3 seconds, and covered by the shutter for 7 seconds, the exposures being controlled by clockwork. Between exposures the gap in the Landolt ring was rotated into one of eight positions and the subject was required to report its position.

Observations were with the right eye only using a 4.2 mm artificial pupil inserted in an optometric test-frame and was as close as possible to the cornea. Beyond it was placed any necessary lens corrections.

The brightness range was between 0.006 and 0.15 millilamberts, and was tested in steps of 0.2 log unit apart, as many steps being made as was necessary to establish an adequate relation between log brightness and the number of correct answers. At each brightness step 16 exposures were tested at each session. Each observer sat for three and occasionally for four sessions. The data for the several sessions were averaged vertically for each subject. Then the data for the several subjects were averaged horizontally in order not to distort the long I-frequency of seeing curves.

The subjects were chosen by the tests already described. There were 6 normals, 3 protanopes, and 7 deuteranopes, and most of the subjects were new, only a few having served in the preceding experiment.

V

The results of the measurements are given in Fig. 6. The curves show the relation between the logarithm of the brightness and the percentage frequency with which the subjects saw correctly the position of the gap in the Landolt ring. The curves are almost parallel. Therefore no matter which frequency of correct seeing is chosen as a criterion, the differences between normal and dichromats remain constant. The data then tell us that to accom-

plish the same visual acuity task (0.29 reciprocal minutes) the deuteranope needs more light than the normal, and the protanope more than the deuteranope.

In section III we saw that the deuteranope has 61.2 per cent and the protanope has 51.0 per cent of the luminosity of the normal in an equal energy spectrum. A 5000°K source gives almost an equal energy spectrum, and for present purposes this approximation is adequate. To bring 61.2 per cent up to the normal of 100 requires a factor of 1.63; this corresponds to an increment of 0.21 log unit in brightness. To bring the protanope 51.0 per cent up to the normal of 100 requires a factor of 1.96, or an increment of 0.29 log unit in brightness. In Fig. 6 in the region between 50 and 60 per cent correct seeing, the displacements are 0.17 and 0.32 log unit respectively.

The measurements from visual acuity therefore agree with the predictions from the threshold luminosity measurements to within 0.03 and 0.04 log unit. These are differences of 7 and 10 per cent, and for work of this kind can be considered adequate confirmation. We can thus accept with confidence the fact that deuteranopes and protanopes lose large fractions of their luminosity in the spectrum. These losses must stem from the nature of colorblindness, and its relation to normal color vision.

VI

There is no completely adequate theory of color vision. However, the one reasonable basis for such a theory has consistently been Young's notion that there are three receptor systems in the retina which may be designated as B, G, and R to indicate their essentially qualitative uniqueness in yielding respectively blue, green, and red sensations when brought into action by light. Each receptor system produces only the sensation unique for it, regardless of the part of the spectrum which sets it into action, and the sensations produced by various parts of the spectrum result from the combined action of these three systems in different degrees. Certain combinations produce specific effects. Thus the combined actions of the G and R systems result in the unique sensation of yellow, while the combined actions of B, G, and R result in the unique sensation of white. Moreover, the action of the receptors contributes brightness as well as color, and the brightness contributions of the three systems are strictly additive.

Young supposed that colorblindness is due to the loss of one of these three receptor systems. Our measurements support this simple and direct formulation for colorblindness. If a protanopehas lost the R receptor system, he should lack not only its color effects but also its brightness contribution, and the loss should correspond to the contribution which the R receptor system makes to the normal luminosity of the spectrum. Since our data show that the protanope suffers a loss of 49 per cent in spectrum luminosity, it would seem that the R system normally contributes 49 per cent of the brightness of an equal energy spectrum. In the same terms, the loss of 39 per cent of spectrum luminosity by the deuteranope corresponds to his loss of the G receptor system, and would indicate that the G system contributes 39 per cent of the normal spectrum brightness.

Even though the simple idea that colorblindness is due to a loss of one receptor system accounts for our luminosity measurements, it does not account

for other equally important aspects of colorblindness, particularly the color sensations. If in normal vision the varying degrees of activity of all three systems, B, G, and R, produce all the varied color sensations, then the loss of one system should reduce the number and alter the quality of these sensations. For example, if the R system is lost, no red sensations should be possible. Loss of the R system should leave the spectral gamut as made up only of blue and green sensations. Moreover, since yellow occurs from the combined activities of the G and R systems, the protanope should have no yellow sensation, and indeed no white sensation either because the action of all three systems is required for this effect.

A similar situation must obtain for the deuteranope also. Having lost the G system, he should see neither yellow nor white as we do. Moreover, the tritanope, because of his lost B system, should also be unable to see white as do normals; to him it should appear yellow because of the action of the G and R systems alone.

None of these consequences of the loss of a receptor system is true. Colorblind persons, beginning with Dalton who described his sensations with great clarity, insist that they see white as uniquely colorless. Their insistence is confirmed by those occasional individuals who are normal in one eye and colorblind in the other. The best described case is that of a tritanope by Dieter, who on comparing the spectrum and other colors with his two eyes characterized white as the same with both eyes. In particular, the neutral points at 575 mμ and 415 mμ were unequivocally described as white. Other instances of monocular colorblindness reported by v. Kries bear out these facts about white.

Moreover, in terms of the loss of a receptor system, neither the deuteranope nor the protanope can have the sensation of yellow. Yet these dichromats consistently describe the spectrum as made up of two hues: blue on the short-wave side of the white neutral point, and yellow on the long-wave side of the neutral point. In addition they record that these two hues are most saturated at the extremes of the spectrum and gradually become unsaturated toward the neutral point which is completely unsaturated as white. In fact, colorblinds make wavelength discriminations in the spectrum on either side of the neutral point not in terms of hue but in terms of saturation. These descriptions are corroborated by v. Kries' monocular colorblind. In short, the sensory reports given by dichromats cannot be accounted for by Young's idea of the simple loss of one receptor system.

The sensations reported by colorblinds may be accounted for by an alternative proposal by Fick. According to this proposal colorblindness involves the transformation of the spectral sensitivity of one receptor system into that of one of the other receptor systems. For example, suppose that the R system is changed so that its senstivity in the spectrum becomes identical with the G system. The altered R receptor system and the normal G system will now be equally stimulated by light of any part of the spectrum. This applies only to the outermost light-receiving end of the receptor elements. The rest of the altered R system beyond the receptor elements will remain as before. Thus regardless of the light which it receives it will still transmit impulses which will result in the production of the unique red sensation. Such an eye will not be able to discriminate hues in the spectrum on the long-wave side of the neutral point because this whole region will be yellow of different degrees of saturation.

This formulation of colorblindness accounts for the sensations which colorblinds have, and for the errors and confusions which they make. Unfortunately it is not supported by our present measurements. For instance, if the R system is not lost, but its sensibility distribution in the spectrum is merely altered, then there should be no loss in the total spectrum luminosity of protanopes. Yet our measurements show a 50 per cent loss. And a similar situation obtains for a deuteranope, whose loss is almost 40 per cent. Thus the idea of a simple loss of one receptor system accounts for the luminosity measurements but completely fails to account for the sensations; whereas the idea of a transformation of one receptor system into another accounts for the sensations, but cannot encompass the luminosity loss data.

Pitt's recent proposal that protanopia represents a simple loss of R whereas deuteranopia represents a transformation of G into R does not resolve this dilemma. Both types of colorblind show a loss of luminosity, and the sensations of the protanope still remain unaccounted for by a mere loss of receptor system.

We thus have two mutually exclusive suggestions for the basis of colorblindness each of which describes only one aspect of the phenomenon. Clearly, a new formulation for colorblindness is required which will combine the virtues of both ideas and eliminate their contradictions.

Summary

Colorblind persons lose brightness as well as color in their vision. For white light, deuteranopes lose about two-fifths of the brightness, while protanopes lose one-half the brightness. Because of these losses in brightness, dichromats also lose visual acuity, particularly at lower cone illuminations. They need more light than normal persons do in order to perform the same visual task. No available theory completely accounts for all the findings.

Discussion

Dr. Blackwell asked Professor Hecht to describe exactly the psychophysical procedure used in determining the terminal thresholds for selected spectral regions.

Professor Hecht replied that his usual psychophysical method was used, in which the observer responded "yes" or "no" to the presence of flashes of light at each of a graduated series of stimulus values.

Dr. Blackwell then asked whether the subjects were responding "yes" to the presence of a stimulus of unspecified color, or whether they were making a chromatic judgment.

Dr. Wald replied that casual interrogation of observers utilizing this method indicated that color was usually detected at the stimulus value accepted as threshold.

Dr. Blackwell then pointed out that by using a psychophysical technique in which the observers were forced to guess, a considerable number of correct reponses could be obtained for stimuli smaller than those considered threshold in the technique used by Hecht. He raised the question

whether sufficient differences between the "Yes-No" threshold and the forced guess threshold for normals and for dichromates might not exist to influence the research under discussion.

The question was asked whether the differences in visual acuity for the normals as opposed to the dichromates were large enough to allow acuity tests to eliminate color defectives.

Professor Hecht answered by showing the range of the data for each of the three color groups: normals, dueteranopes, and protanotes. His data, although for only a few observers, showed very little overlap between the groups. It would appear that additional data for a larger number of dichromates would be required to provide the final answer to this question.

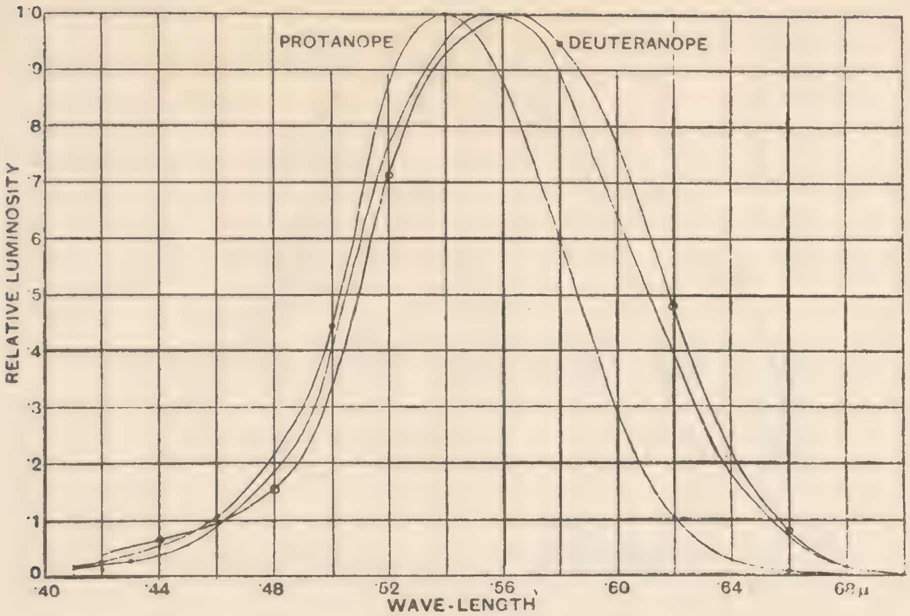
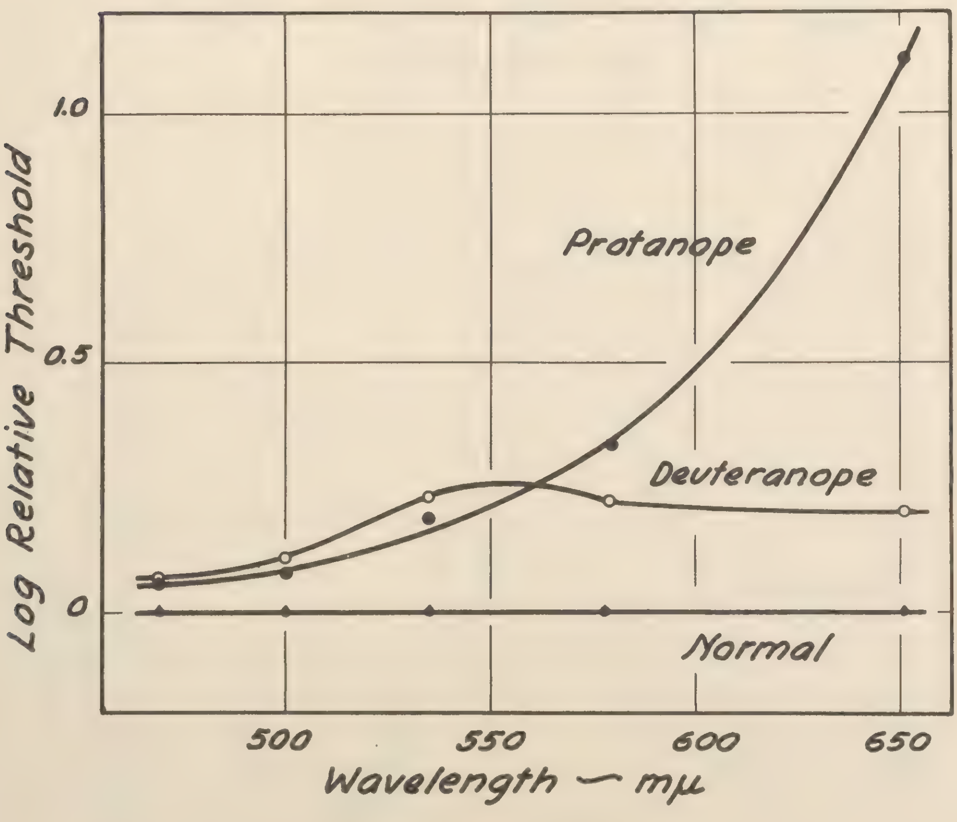


Figure 1.



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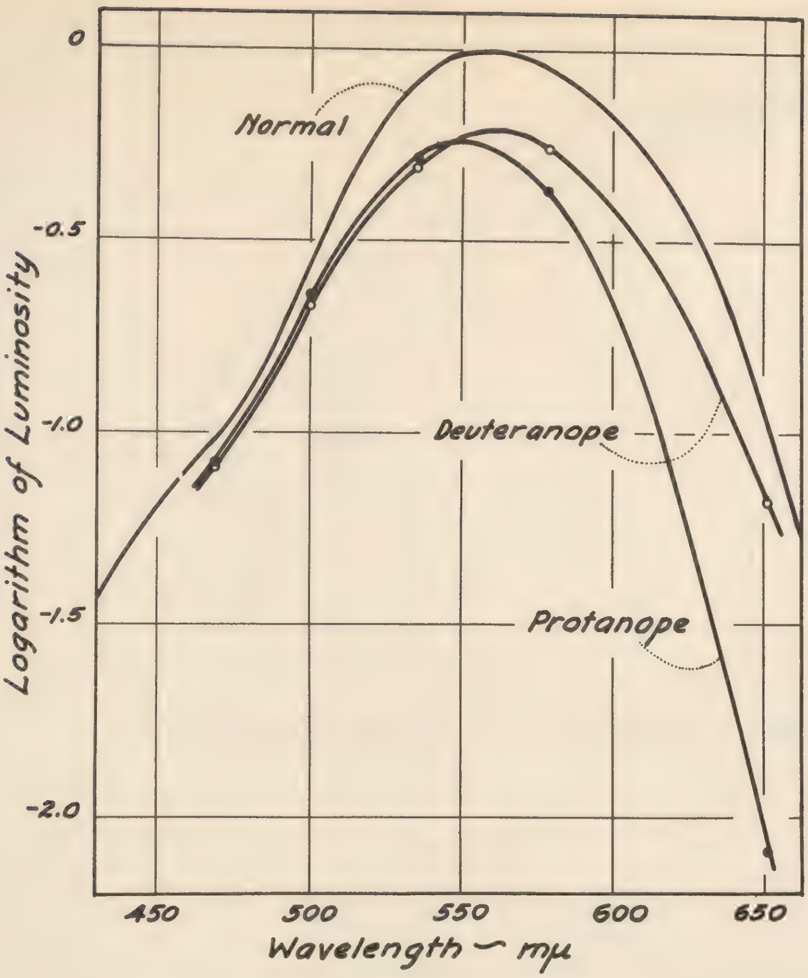

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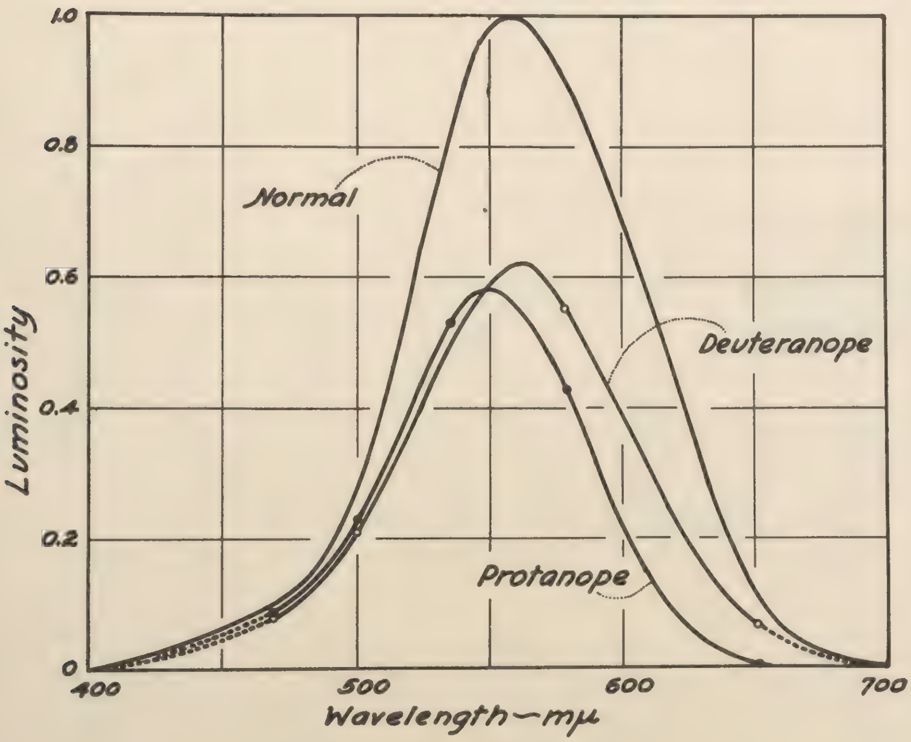

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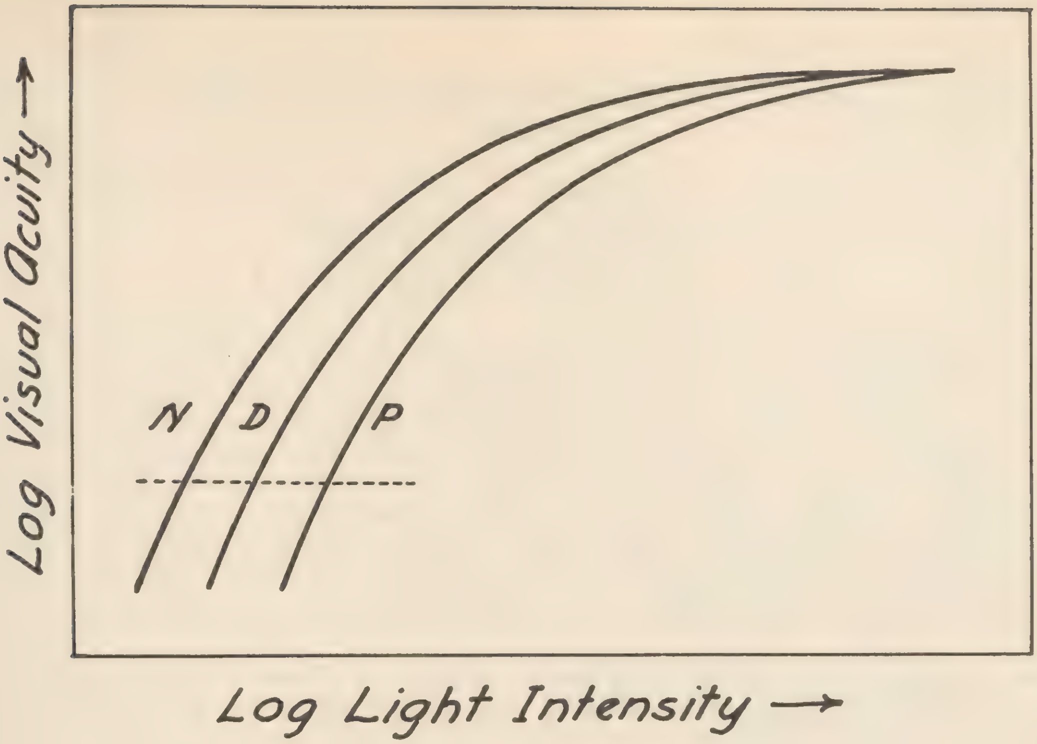

Figure 5.

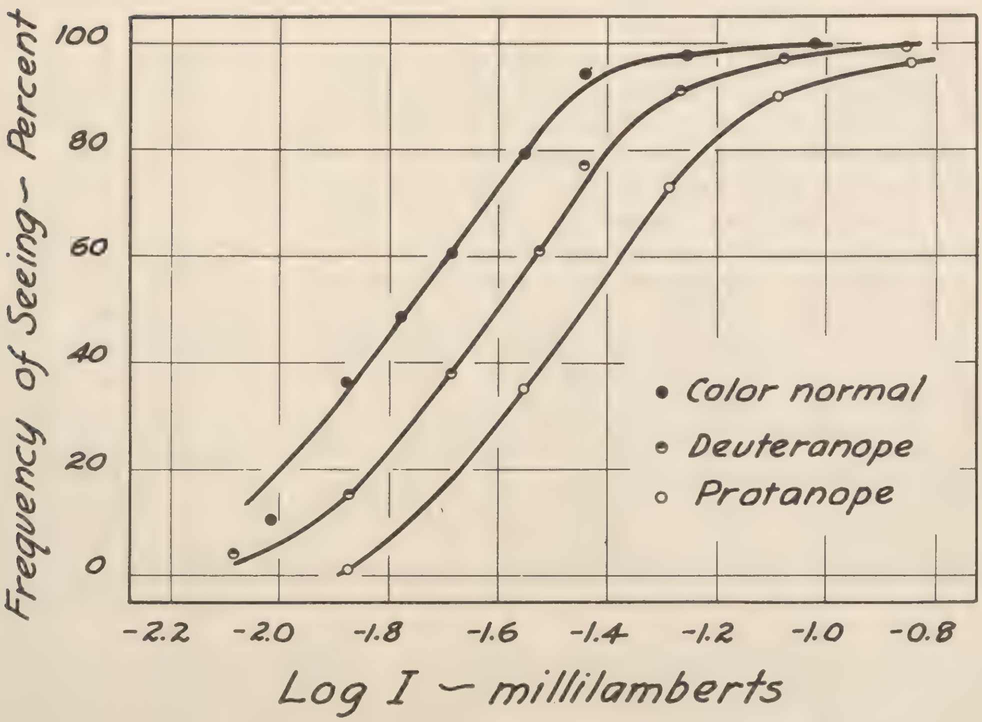

Figure 6.

THE ADAPTATION EFFICIENCY OF THREE TYPES OF GOGGLES

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Although the differences between the scotopic and the photopic functions of the eye have been known for a considerable time, their application to special problems of adaptation for night vision was not made until Professor Miles showed the advantages of the use of red goggles early in the late war. Not long ago this application of red for pre-adaptation purposes was challenged by Lowry and answered by Hecht on the basis that Lowry had used photopic luminosity for one filter and scotopic luminosity for the other. We are not particularly concerned with the theoretical aspects of this controversy but a practical problem was brought to our attention which in some degree involves them.

Assuming the fundamental utility of red goggles as a pre-adaptation device, to what extent does their efficacy depend upon their design? You are all familiar with the type of Navy red adaptation goggles, having soft rubber frame that fits closely to the face around the eyes and effectively exclude all side-light. This type of goggles is not particularly convenient or comfortable, especially in warm weather. We were asked whether a goggle using the same red visual elements but carried in a browrest frame which does not sit close to the face would have sufficient effectiveness to make its use valuable in place of the Navy goggles in situations when perhaps there is less need for precision.

Some sort of answer can be given to this question on a theoretical basis. First, the transmitting medium being identical with that of the Navy goggles is expected to give the same local adaptation effects over that portion of the retinal field on which it is effective. So far, then, as the adaptation is local the browrest type should give results equal to the Navy type. Second, however, the assumption upon which the Navy mounting is based includes the non-local effect of light coming from the side. Possibly we could have determined the proportion of such light, but we should not have known how to evaluate it in terms of local versus general adaptation effects. Third, not all of the side-light is effective merely as side-light. Some of it may act locally by being reflected from the inner surface of the lens directly into the eye. We expect then that depending upon the proportion of such light the browrest type should prove less effective than the Navy type of mounting. Finally, there remains the question whether the effect of such goggles is correlated with its red transmission or with the absolute level of its photopic transmission. Furthermore the particular value of the red goggle is that it permits a high level of central photopic vision during the period in which a dark adaptation level is being acquired.

It is obvious that an opinion on theoretical bases is not a sufficient answer to our particular problem. Therefore we have set up an experimental procedure which we hope will give us more precise information for this particular case and which will have application to similar situations. The first steps in our procedure have been dictated in some measure by the instruments. immediately available. For that reason we are using a N.D.R.C. Adaptometer. This instrument consists essentially of a translucent screen 5" in diameter

which can be illuminated from behind. The amount of illumination is controlled between two limits with a circular neutral wedge. The circular field which has an opaque bar across its middle can be rotated to change the orientation of the central bar. This is used as a check on the reports of the observer. A shutter controlled by the experimenter cuts off light from the stimulus except at the time of presentation.

A small red fixation cross is located 7" above the stimulus disc. This location of the fixation point above the stimulus disc constitutes one defect in the experimental set up which deserves special mention since it involves an arrangement common to several similar devices. It results in the use of the portion of the retina least sensitive for scotopic vision. Our observers reported that when they did not maintain careful fixation they could often see the stimulus at lower intensities. It seems highly probable because of the difficulty of maintaining fixation under these conditions that a considerable degreeof variability may have been introduced by the wandering of fixation. We plan therefore either to shift the point of fixation to a more advantageous position, for example, to right or left at the horizontal level of the stimulus or to instruct the observer to report the minimum visible with roving fixation. We believe that either of these alterations would improve the stability of our observers' reports but we have not worked out a preference between the two.

<u>Pre-Adaptation conditions</u>. Conditions preceeding the determination of a subject's adaptation curve are standardized and controlled. The observer sits in a booth approximately 4' x 6' x 10' high which is lined with "white" canvas having a reflectance of about 80%. The interior of the booth is illuminated from above by a 200-watt light and a 150-watt spot light directed at the rear wall of the booth. Illumination of the front and side walls and the table top in front of the observer is 18 foot candles ± 2 f.c. Illumination on the wall behind the observer is 25 ft. candles. The reason for the higher illumination of the rear wall is to increase the light reflected from the inside surface of the browrest goggles and thus to accentuate this factor. During the period of pre-adaptation the observers were given some task such as reading or playing cards, which would assure "visual activity".

In every case the observer sat in the booth without goggles for five minutes reading or otherwise visually active under the normal illumination specified above. At the end of the five minutes he was instructed to put on one of the three goggles being tested. He wore these goggles under the same conditions of illumination and visual activity for a period of 20 minutes. At the end of that time the illumination in the booth was switched off, the observer was told to remove his goggles, to fixate red cross and to report as soon as he could see the test field which was illuminated to its maximum intensity. When the observer was being tested for the course of adaptation without pre-adaptation goggles, the lights were turned off at the end of the first five minute period. Observations were taken with all four conditions, viz., three types of goggles and no pre-adaptation. At successive observation periods the order of the conditions was varied.

The observer was required to fixate steadily on the red cross above the stimulus field whenever a judgment was called for. Since we are well aware of the difficulty of steady fixation under such conditions a signal was given each time the shutter was opened so that the observer could check his fixation and then report whether or not the field below was visible. After the first report following the period of pre-adaptation that the field was just visible at its maximum intensity the experimenter reduced the intensity

of the stimulus enough so that he could be sure that it would be invisible to the observer. From this level he presented a series of increasing intensities until observer reported the stimulus to be visible. The time was taken and a new series begun from a level below visibility. This procedure was continued until the observer reported that the minimum stimulus was visible. This constituted a full series of measurements.

Results. Our first step in examining results has been to plot light intensity of the just visible stimulus in arbitrary scale units against time in minutes. Since the maximum intensity lies below the level of photopic vision the curves obtained are scotopic curves.

The first and most obvious fact about each group of curves is that preadaptation with any types of goggles shortens the adaptation time. The amount of shortening shows wide individual differences. For some it takes no more than a minute longer for the maximum stimulus to be seen when there is no preadaptation than following use of the goggles; for others the difference is five minutes. The average time is 2 minutes. The difference in adaptation time necessary to see the minimum stimulus is greater. The average adaptation times for the appearance of the maximum and the minimum are given in the table.

Adaptation time for Perception of the Maximum Stimulus

Non Adaptation	Browrest	Navy	Neutral
2.5 ± 1.4	.78 ± .263	.65 ± .292	.85 ± .484

Adaptation time for Perception of the Minimum Stimulus

Non Adaptation	Browrest	Navy	Neutral
19.20 ± 4.09	12.64 ± 2.56	12.05 ± 3.19	15.15 ± 3.66

There is no such clean cut distinction between the goggles. The three curves with pre-adaptation tend to follow very nearly the same course. By inspection it looks as though the curves for pre-adaptation with the Navy type goggle tend to lie on the lower side of the array. To evaluate this more accurately we have averaged the initial time of appearance of the maximum stimulus for each condition, and the times at which the minimum stimulus could just be seen. These values are given in the table and bear out our conclusion that the Navy goggles are slightly more effective than either the browrest or the neutral.

We are presenting only samples of our data which seem representative because at best our material is preliminary. There are indications that some of our controls will have to be improved or altered before conclusive results can be reached. We have groups of curves for example, which do not show as clearly as the ones presented the differentiation between conditions. Some of them indeed do not differentiate between pre-adaptation and no pre-adaptation. We have further evidence however, that some of those failures of the data are due to accidental conditions. For example, it turns out that one of our subjects was recovereing from an alcoholic weekend when he gave adaptation curves that completely interlaced and that ran to much longer than usual times.

The relative merits of red versus neutral filters depends upon other factors. So far as the adaptation effect is concerned the red seems to have little practical advantage. As the table shows the twenty minutes pre-adaptation gives less than two minutes initial advantage and four to seven minutes final advantage.

On the other hand, it may be that red is superior when the subject must be employed during the adaptation period, for example, if he must carry on the ordinary task in a submarine or if in test situation he must read instructions, fill out personnel data blanks, and so forth, or if a group of subjects must be kept under control, then the advantage of the pre-adaptation goggles is obbious. The red goggles seem to give better visibility for such purposes.

However, if a subject is required to do nothing but wait for the onset of night vision as is sometimes the case in experimental or test situations, it will be quicker for him to do so in complete darkness. This fact can be seen directly from the sample curves we have given. Since 20 minutes must be added to the "pre-adaptation" curves to obtain the total time involved but not to the "no adaptation" curves thus the average time from the beginning of pre-adaptation with the Navy goggles to the first visibility of the maximum stimulus is 20.65 minutes whereas from the beginning of adaptation to the same perception level is only two minutes or from the beginning of the pre-adaptation with Navy goggles to the perception of the minimum stimulus is 32 minutes whereas the adaptation time to the same stimulus level is 19 minutes.

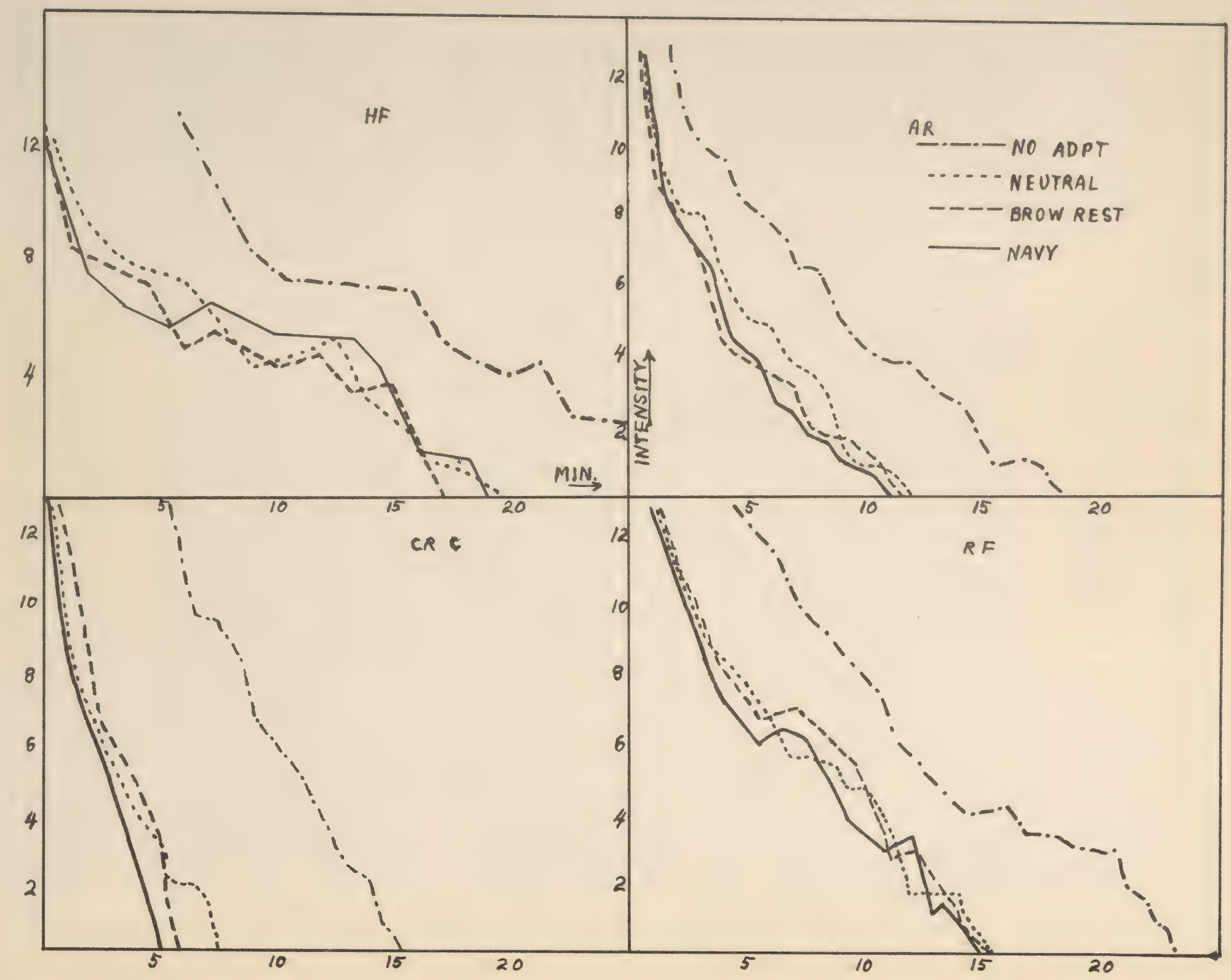
So far as we have gone then the indications are that any one of the three types of goggles will give similar pre-adaptation results. The differences in effectiveness do not warrant the use of the more elaborate and uncomfortable type of goggle when a moderate degree of dark adaptation is desired. Whether or not it is of advantage to use goggles at all will depend upon other factors in the situations.

Discussion

Commander Brown made the point that there was danger in undue generalization from Dr. Dimmick's findings, since under many service conditions much more extreme illumination is encountered than that tested in the experiment. Commander Brown was concerned that although Dr. Dimmick's paper indicated the relative equivalence of the various goggles tested under the conditions used, generality would be assumed by service personnel and serious loss of dark adaptation encountered as a consequence.

Dr. Hecht and Dr. Wald each pointed out that more difference would be expected between the three goggles with higher adaptation brightnesses. They showed that the adaptation brightness used was relatively uncritical to the functions tested.

Lt. Comdr. Farnsworth agreed with Dr. Hecht and Dr. Wald, but remarked that the research reported by Dr. Dimmick had primarily a practical orientation and that the conditions tested as a consequence were those most commonly encountered in the use of the glasses.


HF
AR
NO ADPT
NEUTRAL
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COMPARISON OF THREE TESTS FOR NIGHT VISION

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Because of the prevalence of night operations in the last war, it became imperative almost at the start that some sort of screening test be devised to eliminate individuals whose night vision did not come up to some minimum standard. The device which probably had widest use, in the Navy at least, is that known as the Radium Plaque Adaptometer. This test called for the perception of a simple form against a background of a single brightness. If a subject could distinguish correctly the position of the form in a high percentage of a small number of presentations (18 out of 20)he passed the test; less than this percentage constituted a failure. The present instrument utilizes a single plaque and is provided with a neutral filter to give one lower brightness level. The low brightness is the one used for testing, the high brightness serves for orientation and for checking malingering. The manufacturers of the plaques have given me two values which are supposed to be measurements of the brightness of the plaque, i.e., 14 ml and 38 ml.

For some time the Medical Research Laboratory has had as one of its projects the examination of tests which are in use, the improvement of the current test or the perfection of a substitute test. The principal line of development which has been proposed has been the use of scotometry, as suggested by Livingston, for measuring the efficiency of night vision. Livingston reported that the mappling of the visual field under conditions of scotopic vision yielded conclusive evidence that good night vision is correlated with a small central scotoma and that poor night vision, conversely, is accompanied by a large central scotoma. He urged therefore that scotometry be made the test of night vision. According to his articles it would appear that some use of this method was made in Great Britain.

The technique described by Livingston is tedious and not at all suited for routine testing since it requires an hour to an hour and a half for each subject. Livingston himself suggested the possibility of a modified form of scotometry by means of an iris diaphragm placed in front of a phosphorescent plaque having a red fixation point at the center. The minimum opening of the diaphragm that is just perceptible under conditions of scotopic vision is taken as a measure of the size of the central scotoma. Capt. Korb had such a device built and Lt. Comdr. Sulzman began a comparison of these several methods of evaluating night vision. As a matter of fact the present project is an outgrowth and continuation of his earlier project. A more complete discussion of the background of the project will be found in "A Study of the Physiological Blind-Spot of the Dark-Adapted Fovea" BuMed Project X-492 and Project X-614, 1 March '46.

Our present attack upon the problem has been, first of all, to make the procedures of scotometry more efficient. To this end we have worked out certain modifications of the campimeter. Our field is made of a four-foot-square of plywood covered with several layers of baize to give it a cushioned surface. Through a 3/4" hole at the center protrudes a red fixation light. For each map of the field of vision, a piece of paper about 2 ft. square with hole at the center is thumbtacked to the front of the campimeter. As a stimulus we are using radium-activated phosphor plaques 1" in diameter of an

intensity 20 times that of the Navy Radium Plaque Adaptometer, that is, 14 to 38 micromillilamberts X 20. These plaques are of a size and intensity to facilitate their accurate photometric measurement. In use, one of them is inclosed in a brass mount which masks the plaque to a disc of 3 millimeters. On the back of the mount is a brass point with which the record sheet can be punctured to indicate the spot at which any particular observation is made. The marking of the record sheet is facilitated by the padding of the campimeter field.

In mapping the central scotoma, the stimulus is moved from the periphery toward the fixation point at a constant rate of speed until the observer reports that it disappears. At present 12 radii are being used. When one set of observations has been completed the record sheet is changed and the stimulus is moved from the fixation point out until the observer reports that it is visible. Separate maps are made with each eye. We propose to map the scotomata of our observers with various intensities by using filters and with various sizes of the stimulus.

Only about a dozen observers have been examined so far, hence, the results are merely indicative. Sample maps are shown, of a small scotoma and of a relatively large normal scotoma. The large differences between the scotoma as mapped by the "In" direction as against the "Out" direction indicates that the boundary of the scotoma is a gradient. Its size depends therefore upon several factors so that there are many, rather than only one, scotomata. It should be possible for example, to match the in-going and out-going maps by proper variations of size and intensity of the stimulus. There will, probably, be an inner and outer limit of this gradient.

We have not forgotten that our initial project is to compare the three measures of night vision, therefore every observer is tested also with a diaphragm scotometer and with the Radium Plaque Adaptometer. With the brightness level of the plaque now in the instrument modified by the filter from the R.P.A. it happens that the diaphragm determinations of the scotomata tend to fall between the "in" and "out" determinations with the standard compimeter but nearer to the "in" map. This is a matter of chance for it is evident that the size of the diaphragm determination will necessarily follow the gradient with shifts in intensity of the field. With a brighter field we should be able to duplicate the boundaries indicated by the "in" method and with a dimmer stimulus those of the "out" method.

In previous experiments it seemed to have been assumed that, since the central scotoma is an irregular area, the bright central disc will be perceived first at those points where the irregular out-lines are crossed by the circumference of the circle. The few observations we have made seem to deny the validity of this assumption. When the bright area is seen at all, it covers the whole central field. This raises another interesting problem, namely: How much of the periphery of the scotoma must be excited in order for the central area to be perceived!

It is evident from our data that by means of the diaphragm device with the correct field brightness we can make quickly a close approximation of the size of the central scotoma under a given set of conditions. That is to say, the data obtained from the Korb device correlate closely with that from the Livingston screen. However, in their present forms neither procedure is suitable for use as a practical service test because at present there is no way to control or detect malingering. Since any measure of the size and location of

the scotoma depends upon steady fixation, a subject can either pass or fail, falsely, if he chooses. Although with the diaphragm instrument an area of 2 to 3 degrees is completely invisible with fixation on the center point it can clearly be seen when the fixation point is moved to one side. Until some modification is devised to control this factor the diaphragm cannot be used as a test, though as we have indicated it affords a means for certain fundamental observations concerning the distribution of scotopic sensitivity and of the integration of scotopic stimuli.

Data for comparing the results of scotometry and those with the Radium Plaque Adaptometer is as yet too inadequate to offer any figures but there are indications that an inverse relation will show up between area of scotoma and correct responses on the RPA. I say this because we have found that subjects with small scotomata have good RPA scores and the two subjects with large scotomata have poor RPA scores.

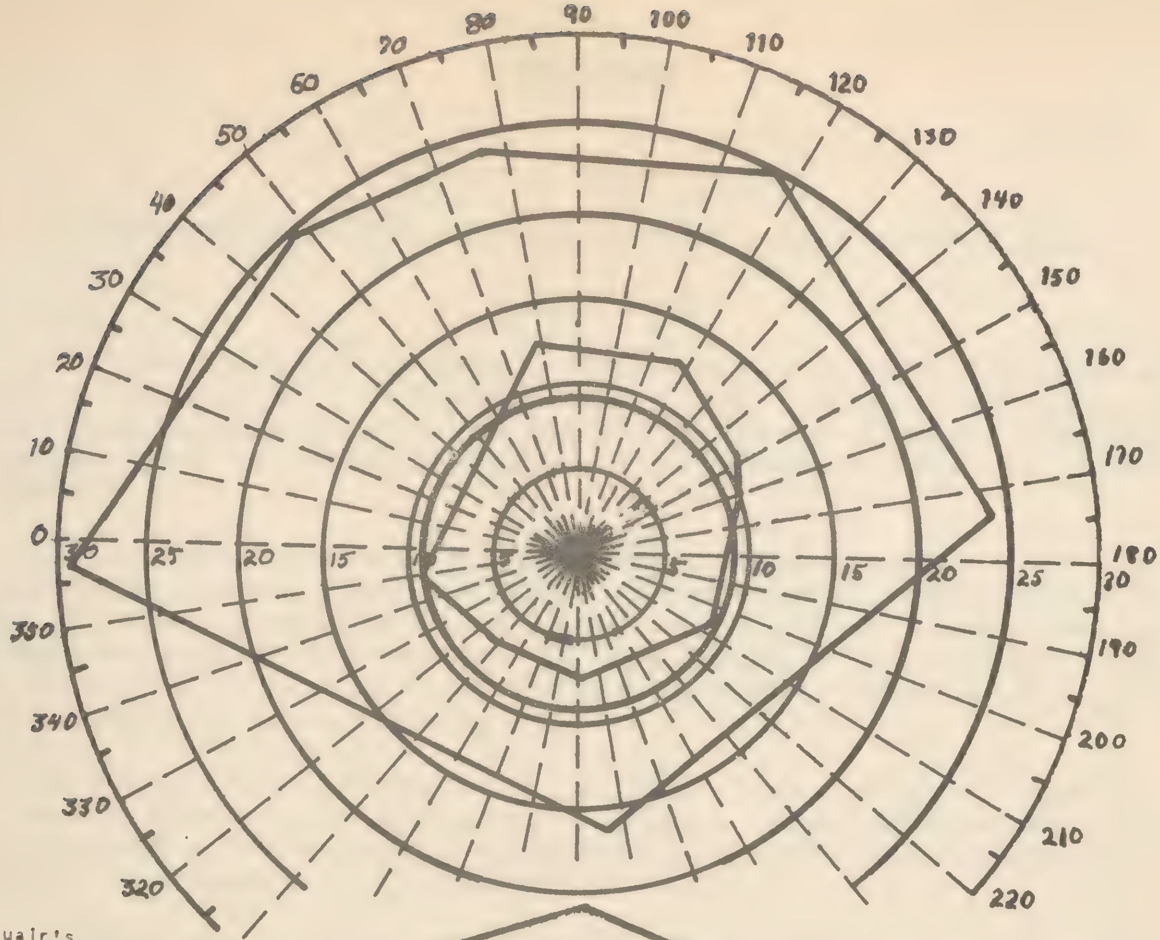
Discussion

Dr. Scobee questioned Dr. Dimmick further concerning the existence of a difference in scotoma size, depending upon whether the measurements were made from the inside out or from the outside in.

Dr. Dimmick made the suggestion that a correction be applied in the test so that equivalent results could be obtained whether the in or out method of testing were used.

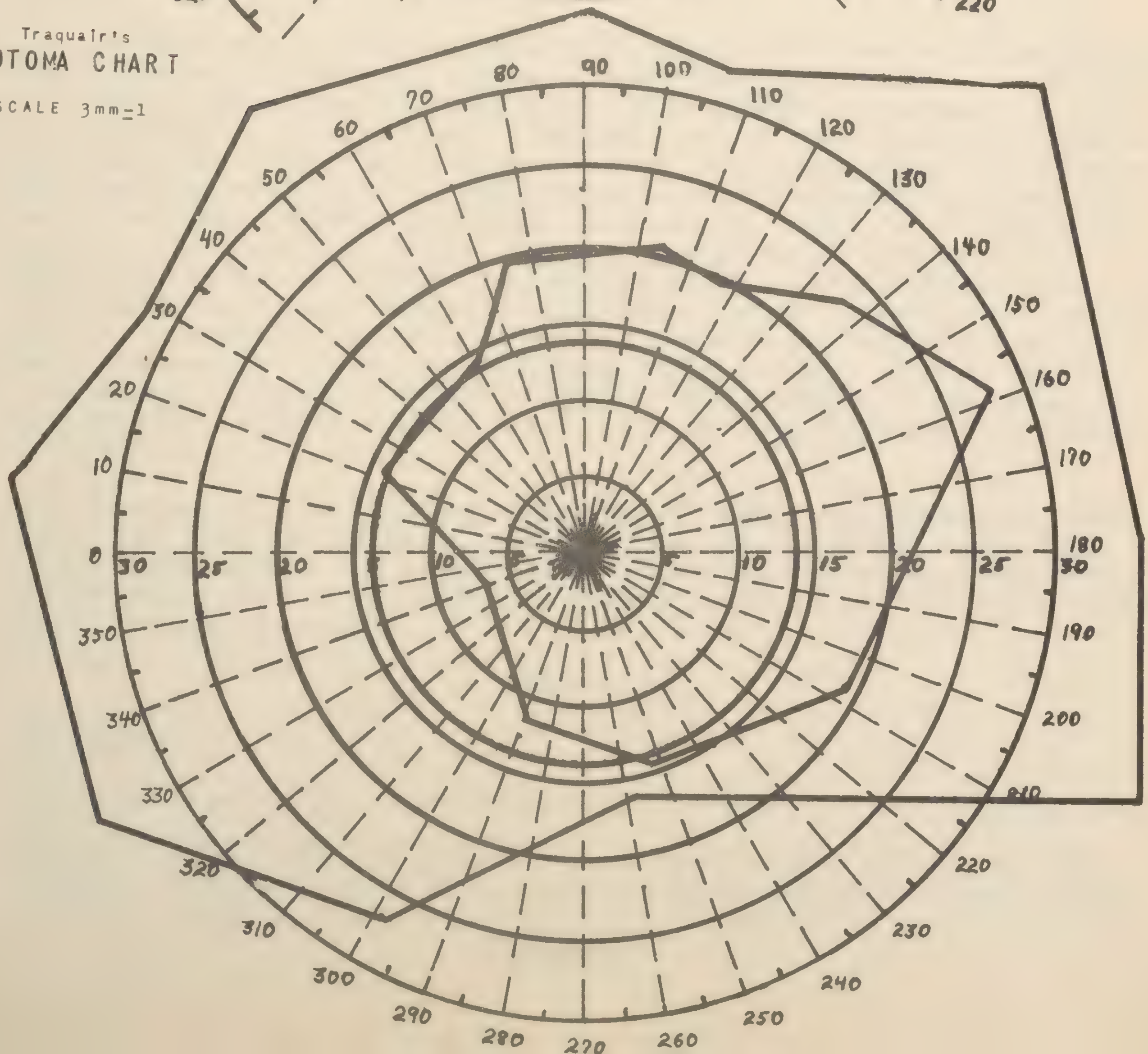
Dr. Wald emphasized that the method of scotometry utilized really was a measurement of iso-threshold lines. He suggested that perhaps actually plotting thresholds as a function of retinal position would yield more reliable data than the data obtained with the scotometers.

Dr. Dimmick agreed that a measurement of threshold as a function of position is the most exact way to plot the size of the central scotoma, but remarked that for clinical practice the rapid means of scotometry available in the Korb instrument was very valuable.



Traquair's
SCOTOMA CHART

SCALE 3mm=1



Abstract of paper entitled

ACCOMMODATION, CONVERGENCE, AND STEROSCOPIC VISION IN DIM LIGHT*

George Wald

Dr. Wald explained that the experiments he was reporting were undertaken under an OSRD contract. He explained that his laboratory did not intend to pursue experiments along this line and that he was anxious that the data be presented before the Vision Committee so that interest in this area could be stimulated.

The stimulus to the research undertaken at Harvard was the result obtained in British and French researches that performance with binoculars at night was often improved by a more negative setting of the oculars than was found advantageous in the daytime. Dr. Wald undertook to verify this finding and reported his results before the Vision Committee. (See Minutes and Proceedings of the Sixteenth Meeting.)

In conducting these experiments, Dr. Wald discovered certain observers who showed large positive settings at night with respect to day-time, and also observers who showed negative settings much larger than could be explained on the basis of chromatic or spherical aberration.

Dr. Wald came to the conclusion that involuntary accommodation was present with these observers and that the observers were unable to accommodate in dim light. In order to verify this fact further, Dr. Wald performed experiments in which the brightness required to reach a constant level of resolution was determined with binocular oculars set at various values. The data obtained for observers who demonstrated involuntary accommodation at night indicated that each observer required a minimum brightness for a constant resolution at some particular ocular setting; ocular settings either more negative or more positive than the optimal one resulted in higher brightness being required for a given resolution. Further, it was shown that the optimum ocular setting did not correspond to the ocular setting selected in the daytime. Some observers showed an optimum focus setting at quite different dioptric settings than others. Dr. Wald took this to indicate that different observers were in a state of fixed focus at night, the fixed focus being different for various observers.

Experimental runs utilizing hematropine to paralyze accommodation yielded functional relations similar to those obtained with the normal eye at night. On the other hand, in the daytime, it was shown that the eye was capable of accommodating for 5 or 6 diopters of negative power, but was not able to accommodate for positive power.

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Discussion:

Dr. Tousey reported that measurements of "night myopia" at NRL indicated that

*A full account of this research can be obtained from the article entitled, "Change in Refractive Power of the Human Eye in Dim and Bright Light", Wald, G. and D.R. Griffin, JOSA, 1947, Vol. 37, No. 5: 321-336.

spherical aberration might account for this phenomenon.

Dr. Wald described the published data of Otero from Madrid, and emphasized that Otero's results unknown to him until very recently, confirmed his results to "an almost embarrassing degree". Otero's results, Dr. Wald said, indicated that approximately 0.25 diopters of night myopia were caused by spherical aberration, and o.50 by chromatic aberration, the remainder being attributable to involuntary accommodation.

Dr. Tousey asked the question whther hematropine might influence the eye in some way other than paralyzing accommodation. He raised the question whether perhaps it might change the shape of the eye thus introducing additional aberrations.

Dr. Blackwell reported an analysis made on the Tiffany data which indicated the possibility that fluctuations in binocular fixation were responsible for the contrast area function for unlimited stimulus durations. As a consequence of this analysis, a measure of the degree of binocular fluctuations as a function of adaptation brightness was inferred. The measurements indicated that fluctuations of convergence increased with a decrease in adaptation brightness, reaching large-scale magnitude at scotopic brightness levels. This inference, unsupported by experimental data, was in agreement with Dr. Wald's discovery that the accommodation of the eye becomes fixed in dim light, because of the linkage between accommodation and convergence.

REPORT OF THE SUBCOMMITTEE ON VISUAL TESTING

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This will be a brief report of the progress made and the current status of studies of visual acuity testing being conducted by the Personnel Research Section and the Sub-committee on Visual Testing. It is not intended to represent all the current activities of the Sub-committee.

No data will be presented at this time since the analysis of data of the first two studies we conducted is not complete and reports are still being written. This work has been slowed by attrition in our staff and the necessity to give our attention to projects of higher priority within our organization. However, our interest has not waned, and we hope to come out with a full report in the near future.

The current studies of visual acuity testing grew out of general dissatisfaction with the results of administration of clinical letter tests such as the Snellen test.

From a broad point of view, the ultimate need of the armed forces is analysis of the visual requirements of the many jobs, measurement of each man's basic visual abilities, and, very important, discovery of the relationship between measured visual ability and performance on the job. Fundamental to this process of search is the development of sound measuring instruments. One cannot learn much more about the visual requirements of a job than one knows about basic visual abilities and their measurement in large populations.

The studies I shall outline were designed to answer the questions:

1. What are the factors in visual acuity, as measured in a battery of tests including many types of test objects?

2. What are the reliabilities of these tests?

3. What method of scoring will prove most reliable and meaningful?

4. What are the effects of practice, i.e., taking the tests over and over again, on test score.

5. What effects do the range of stimuli, distributions of their relative difficulty, and mode of their presentation have upon the result?

6. Among other source of error, what variation can be attributed to different examiners and test booths?

Two studies have been made to date: (1) A study of the factors in visual acuity, and (2) A study of the effects of practice on visual acuity. In both the clinical chart tests presented at 20 feet were the measuring instruments.

The methods employed were observed at a previous meeting of the Vision Committee, held at Ft. Dix. N.J., and were reported in the Minutes and Procedures of that meeting, 14-15 October 46. Time does not permit a complete review of the methodology at this time. In brief, five types of test object,

thought to cover all the aspects of acuity, were thrown into 13 chart tests and administered under controlled conditions to several hundred soldiers. The test objects employed were: letters, non-letter resolution objects (dots, lines, and checkerboard grids), contrast discrimination objects, forms and a vernier acuity object.

The conditions of booth lighting and other administrative standards employed in the studies deserve special mention. Our standards were the result of the excellent work of the Sub-committee on Visual Testing in pulling together the results of years of research to create optimal testing conditions.

The results of the first study may be briefly outlined. A preview of them was conducted at Personnel Research Section in a meeting of the Sub-committee on Visual Testing, 15 November 47 and a brief of the meeting is contained in the minutes of 14-15 October page 49 and forward. A factorial analysis has been completed. This statistical method will not be described, except to say, that it is a method of reviewing the intercorrelations of the test scores whereby the different aspects measured by the tests are identified and how much of each test score is contributed by each of the aspects or factors. Three factors were discovered which would account for practically all the test score variance.

They have been tentatively named: Resolution, Brightness discrimination, and form. Letter tests and these using dots, lines, and checkerboard grids seem to measure resolution predominantly. The tests employing brightness objects are most heavily loaded on this factor. Finally, the form factor is represented in tests so named. It should be kept in mind that none of the tests measured any of the factors in a pure way. Each test is shown by the analysis to measure all three factors to a varying degree. For example the letter tests measure some form and some of the non-letter resolution tests measure some brightness. And, as to the naming of the factors, we hold no brief for their identity by name. In the light of other evidence it will be quite possible to identify the factors as logic may dictate. Dr. Hecht and others contended that brightness discrimination is the fundamental function and such may be the case although our battery of tests seems most heavily loaded on the resolution factor.

Other interesting results have been the finding of satisfactory reliability for most of the tests with exceptions appearing correctable if the test designs are improved. Examination of the distributions of test scores show the range of items presented is in many cases too narrow to adequately measure the total population. Item difficulty study has demonstrated some very interesting errors of measurement growing out of the method of presentation. There seems to be a tendency for the items to become progressively difficult within the same size of stimulus values. However, much of this must await complete presentation of the data.

The second study-that of the effects of practice-employed the same testing facility with a few new controls apropos this study.

Analysis to date reveals that while some improvement in mean score is apparent on most tests such improvement is slight.

VISUAL EXAMINATION OF FLYERS RETURNED FROM COMBAT*

Henry A. Imus

INTRODUCTION

In May 1944 a research project was established by the Bureau of Medicine & Surgery at the School of Aviation Medicine and Research, Pensacola, Florida, to evaluate the visual portion of the flight physical examination. The visual standards for Naval Aviation had been established some 20 years previously upon an arbitrary basis, using the best ophthalmological judgment at the time as to what constituted normal visual performance. Since then slight modifications have been made from time to time but no attempt has been made to justify the standards as set. It is true, however, that the standards selected were fairly good and represented what had been established clinically as within "normal" limits, with some exceptions.

An evaluation study may be defined in several ways. First, it can be determined to what extent the standards as established were met by the repeated flight physical examinations. This procedure is complicated by the fact that the eyes change slowly, with great individual differences, so that some who qualified upon entrance may fall below standard at some later date. Furthermore, any who fell much below standard would have been disqualified on some annual or change of duty flight physical examination.

Second, the evaluation of the flight physical examination might be defined as the study of the predictive efficiency for performance in handling an aircraft. For example, can a man with 20/40 visual acuity do as well as a man with 20/20 visual acuity? The difficulty with this approach is the fact that there are no reliable criteria of performance in flying. The judgments as to what constitutes good flying are nearly as numerous as the flight instructors. Serious attempts have been made to standardize judgements of flight performance, and the CAA has attempted elaborate objective methods of evaluating the manipulation of aircraft, both in the air and on the ground. A study has been undertaken in which persons with defective vision are selected and taught to fly. Unfortunately for science, too few persons with defective vision are willing to attempt the flight training without wearing glasses which correct their vision to normal. As far as Naval Aviation is concerned, the task of the aviator is much more than sheer manipulation of aircraft. He must see, recognize and attempt to destroy enemy aircraft or other targets, see and avoid enemy aircraft which upon a specific mission or outnumbered, return to and find a roving base. Thus, a thorough job analysis of Naval Aviation would be a worthwhile corollary of this project.

The method selected for this project is similar to that used by the British--a study of the men who lived through combat and remained in flying status. It is assumed that visual factors of great importance for Naval Aviation would cluster around some level, while those not critically important would show a wide distribution of values in a population sample selected at random from a large group of Naval aviators who had returned from combat or operational duty.

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* Based on BuMed Research Project No. X-395, Report No. Two, May 27, 1947

Beginning at the Naval Air Station, Pensacola, Florida, in June 1945, all Naval aviators reporting aboard from combat or patrol duty were given a complete visual examination. After about two months of operation, it was discovered that patrol pilots were in the large majority. Arrangements were made then to ship the testing equipment to the Naval Air Station, Jacksonville, Florida, where tests were continued for ten days. At the end of this time all of the available pilots at the Mainside had been examined, so the equipment was moved again to Lee Field near Green Cove Springs, Florida. Operations were continued at this Station for about six weeks, during which time about 100 aviators were examined. Since this was a fighter training station, most of the subjects had had combat experience. By this time the Station was about to be released to accommodate the Fleet Reserve and the aviation group moved to Opalocka, Florida. Although the number of subjects examined now exceeded 200, including about an equal number of fighter and patrol pilots, it seemed desirable to increase the number to 250, at least, and to draw upon a sample of dive-bomber pilots. Consequently, another move was made to Cecil Field, near Jacksonville. The number of subjects was brought up to 260 before this field was closed.

EQUIPMENT AND PROCEDURES

The visual tests used in this experiment include all of the tests used in the usual flight physical examination and a number of additional tests. In summary, the tests used are: visual acuity, heterophoria, fusional amplitudes, refraction, measurements of accomodation, convergence, and interpupillary distance, color vision, field of vision, inspection and ophthalmoscopic examination. The measurement of aniseikonia, two additional measures of depth perception and the Bausch & Lomb Ortho-Rater test were also included.

1. Visual Acuity: The standard Grow Chart was used for the measurement of visual acuity. The chart was illuminated by one 200-watt bulb which was enclosed in a parabolic porcelain reflector and which was placed above and in front of the chart at a distance of one meter. Repeated measurements with the MacBeth Illuminometer showed that the apparent brightness of the chart at the level of the bottom row of 20/20 letters was 25 apparent foot candles. The variations above and below this position on the chart were negligible. No other illumination was used in the room during this test.

   For near vision, the Lebensohn Near Point card was used. Just the section containing reduced Snellen letters was used, which was arranged in steps of 20/13, 20/16, 20/20, 20/25, 20/30, 20/40, etc. The right and left eyes were tested separately, and then both eyes together. The subjects were required to read the lines backwards and forwards.

2. Heterophoria: The lateral phorias at 20 feet were measured according to standard procedures with a white Maddox rod before the left eye and Risley prisms before the right eye while the subject was fixating a small circular source of light 1 cm. in diameter. The vertical phorias were measured with a Steven's Phorometer graded in tenths of prism diopters up to 2.0 prism diopters. The lateral and vertical phorias for near vision were measured in a similar manner while the subject was fixating a pin-point of light, 1 mm. in diameter, at a distance of 16 inches.

3. Fusional Amplitudes: The measurements of fusional amplitudes, both lateral and vertical, for distant and near vision, were made according to standard ophthalmological practice, using the same spot of light for fixation which had been used in the phoria tests. These measurements followed the phoria tests, and were made in the following order: positive vertical divergence, negative vertical divergence, abduction (divergence), adduction (convergence), negative fusional reserve (divergence at 16 inches), and positive fusional reserve (convergence at 16 inches).

4. Depth Perception: The Howard-Dolman apparatus was used to measure depth perception at a distance of 20 feet according to standard procedures. The apparatus was set up at eye level with the subject seated. The rods were illuminated from above by the same 200-watt lamp and reflector used in the tests of visual acuity previously described. This prevented any cues as to the relative position of the rods which might result from differential illumination of them. With the rods widely separated, the subject was allowed to adjust the rods until they were apparently even. The movable rod was set alternately back and in front of the fixed rod, and five trials were allowed. If the subject was extremely erratic, ten trials were allowed. The score was the average of the five or ten trials.

5. Color Vision: The second edition of the AO Pseudo-Isochromatic plates was used for the testing of color perception. This was done because many of the plates were found to be better than those of the first edition, and because the new arrangement of the plates would eliminate any memory patterns which might have been developed from the four-plate arrangement of the first edition.

6. Field of Vision: The field of vision for each eye was determined by the confrontation test. A small light, from the hand ophthalmoscope, was brought in from beyond the limits of peripheral vision until the subject reported seeing the light. This was done in the horizontal, vertical and oblique meridians of each eye, while the other was covered.

7. Inspection and Ophthalmoscopic Examination: When all visual and perceptual tests had been completed, the external inspection and internal ophthalmoscopic examinations were performed. The condition of the lids, palpebral and bulbar conjunctivae, sclera and cornea was noted, and the pupillary reactions to light, accommodation and convergence were observed.

8. Refraction: Because it was impossible to administer cycloplegics to aviators in flying status, the measures of refraction were obtained according to standard subjective methods using the so-called "fogging" technique and the crossed cylinder technique. The Duochrome test of the A.O. Projecto-C-Chart was used to determine the proper spherical correction, reducing the plus spheres until the letters on the red and green background appeared equally distinct or slightly favoring the red. The final prescription, then, consisted of the astigmatic correction obtained by the crossed-cylinder technique and the spherical correction obtained by the Duochrome test and modified by the binocular addition of plus sphere, if necessary.

9. The Bausch & Lomb Ortho-Rater: This industrial vision screening device was developed to test some of the characteristics of vision that may be important for efficient prosecution of certain industrial tasks. Inasmuch

as the reliability and validity of this instrument had been tested, using Naval personnel at Pensacola, it was decided to administer these 12 tests of near and far vision along with the rest of the battery of visual tests.

10. Description of the Interpupillometer: The NDRC Interpupillometer consists of a lacquered lucite box in which are mounted an adjustable eyepiece assembly, a front-surfaced mirror and lights for the illumination of the pupils.

The eyepiece assembly consists of two differently shaped apertures, each carrying vertical hairlines etched in glass, the separation and adjustment of which is accomplished by means of lead screws. The measurement of the separation of the hairlines is obtained from a vernier scale cut on the upper edge of the assembly. Two small light bulbs below this assembly illuminate the eyes of the subject being measured.

The subject observes the reflections of his own eyes and of the apertures in a front surfaced mirror mounted at the rear of the box and adjusts the lead screws until each vertical hairline bisects each pupil. Three to five independent settings are obtained and the median value is recorded as the measure.

11. Description of the Stereo-Vertical Test[1]: The stereo-vertical test, as administered with the Projection Eikonometer, provides a measure of stereopsis, the ability of a subject to discern depth. In this test, two line images are projected simultaneously upon a vertical screen. The images are polarized so that when viewed by the subject through proper polaroid viewing filters only one line is visible to each eye. The subject fuses these, thus perceiving a single line.

The lines are rotated in opposite directions, so that the binocularly fused image appears to the subject to be tilted from the vertical either toward or away from him at the top. A motor drive slowly returns the lines toward the vertical. The subject signals by pressing a button switch at the instant the fused line appears to him to be vertical. The switch stops the motor instantaneously and the angle which the line makes with the vertical at the time of the subject's response is recorded by the examiner. A scale, graduated in tenths of degrees from 0° to 20°, is visible to the examiner and 10° corresponds to the true stereoscopic vertical. The lines are rotated in the opposite direction before starting the next trial.

The test consists of three "runs" of ten settings each, following four to six or more practice trials. Successive settings are made in alternate directions. In each "run" there are two distinct groups of five settings each, recorded in adjacent columns in the record card. For one group the line is tipped away from the subject initially, for the other toward him.

The raw score, then, is the sum of the sum of the deviations about the medians of the six sets of five trials. The raw score is converted to a standard score by reference to a table of standard scores.

1 Imus, H. A., "Manual for use in the Selection of Fire Controlmen (O)" OSRD Report No. 4050, 1944.

[redacted]

12. <u>The Verhoeff Stereopter:</u> The Verhoeff Stereopter is designed in such a way as to introduce misleading monocular clues of relative depth or distance and to make binocular parallax the only correct evidence of relative separation. In addition, a uniform illumination eliminates cues resulting from brightness contrast, and the simple design of the test objects and the background offers no other cues as to the relative position of the sticks. Thus, if the subject judges relative position on the basis of relative size he will be wrong six out of eight times.

The Verhoeff Stereopter consists of a small, self-illuminated ground glass aperture in front of which can be made to appear three short bars of different widths, one of which is displaced toward or away from the observer by a short distance.

The Stereopter is held at a distance of 2 meters at eye level. Four settings are presented in random order, the target being lowered to change setting and to check the response after each judgment. The instrument is inverted in order to present the remaining four settings following the same procedure. The test is terminated when all eight settings are identified correctly. If any errors are made, the examiner moves forward to the 1 meter position. The same procedure is followed at this distance. If the subject makes one or more errors, the examiner moves forward to the one-half meter position, and the test is repeated a third time. The distance at which the subject makes all correct responses is recorded as his score.

STATISTICAL TREATMENT OF THE DATA

Distributions and percentile scores were obtained for all of the measures taken in this experiment with the exception of the color vision test using the AO Pseudo-Isochromatic Plates, and the cycle-aniseikonic measures.

Relationships between various tests were investigated by arranging the frequencies for any given pair of variables in a scatter plot (Cureton-Dunlap Correlational Chart), and computing the coefficient of correlation.

Data on the reliability and validity of some of the tests were obtained in a previous experiment by the author or were obtained from other sources as acknowledged elsewhere in this report.

RESULTS

<u>Description of Subjects:</u> The subjects of this investigation were 118 combat and 132 patrol pilots who had returned from combat or operational duty and were receiving additional or refresher training or were being assigned to shore duty according to Naval custom. They ranged in age from 20 to 30 years, with the exception of two or three pilots who were up to 40 years of age. See Table 1 and Figure 1 for the distribution and cumulative frequency in per cent of the ages. The median age is slightly over 23 years with 96 per cent at 28 years or less. In Table 2 it is shown that below the age of 25 years the frequency of pilots having patrol duty was higher than that for combat duty. This difference was caused by the fact that at the time the experiment was started large numbers of patrol pilots were being returned from patrol duty off the coast of South America to Pensacola. Here they were given refresher training and were reclassified before being sent out to the Pacific.

[redacted]

The distribution of the number of flight hours logged by the subjects of this investigation shown in Table 3 and Figure 2 indicates the range of service given. The data of Table 3 are redistributed in Table 4 in order to show the relative flight experience between the "Combat" and "Patrol" pilots. It is noted that 61.4 per cent of the "Patrol" pilots had less than 1,000 hours, whereas 86.3 per cent of the "Combat" pilots had 1,500 hours or less. Above 1,500 hours the groups are equivalent. Again, the lower number of flight hours logged by the "Patrol" pilots is attributed to the sudden influx of such pilots being transferred through Pensacola from the South American Patrol.

The type of duty and kind of plane flown by the subjects is shown in Table 5, together with the number of tours of duty. The "Combat" group handled the fighter, dive bomber or torpedo bomber chiefly and over one-third of them served two tours of duty. This would be expected because of the shorter tour of duty as compared to that for "Patrol" pilots. The latter handled the medium land bomber, chiefly, and about one-fifth of them served more than one tour of duty. Most of the medium land bomber group were on the South American Patrol.

As would be expected, the "Patrol" pilots served the greater number of months of duty as compared with the "Combat" group. Of the latter group, 72.8 per cent served 14 months or less whereas for the "Patrol" group 75.1 per cent served 20 months or less. These data are shown in Tables 6 and 7 and illustrated in Figures 3 and 4. The bi-modal distribution for the "Patrol" group is caused by the inclusion of some fifty pilots who were brought back from the South American Patrol following cessation of the hostilities in the European zone.

The "Combat" pilots had a wide range of experience as indicated by the number of combat sorties in which they participated shown in Table 8. The Table shows that 32.2 per cent took part in 30 or less sorties, 79.6 per cent participated in 70 sorties or less, and that a few ran up as high as 150 sorties. A sortie was defined as a mission against enemy targets.

Clinical Tests: The data of all the clinical examinations are summarized and presented in Table 9, which shows the mean score, the standard error of the distribution and the 5th percentile score for each of the clinical tests.

In visual acuity obtained by the clinical method it is shown that the mean is approximately 20/15 for each eye and nearly 20/13 for both eyes. The standard error in each case is approximately two arbitrary scale units. Attention is called especially to the 5th percentile score which is 20/20. This shows that the distribution of scores of acuity are definitely skewed toward the upper levels. Such a distribution is expected, however, since the basic selection cut-off score was established at 20/20.

For near vision, the mean is approximately 20/15 for each eye and slightly better for both eyes, 20/14.5. The 5th percentile score is 20/16 in each case.

For far and near vertical phoria the mean is less than one-quarter prism diopter of left hyperphoria. The standard error for near is almost twice that for far, and the 5th percentile score is 0.6 prism diopters for far and 1.0 prism diopters for near. This is consistent with the general tendency for vertical phoria to be greater and more variable for near vision.

For distant vision the mean lateral phoria is slightly on the esophoric side, (0.36 prism diopters), but 95 per cent of the scores lie within 4.0 prism

TABLE 1. The Distribution and Cumulative Frequency (in per cent) of the Ages of the Subjects. N is 250.

Age	Frequency	Cumulative Per Cent
30	4	100.0
29	5	98.4
28	19	96.4
27	14	88.8
26	23	83.2
25	22	74.0
24	47	65.2
23	49	46.4
22	35	26.8
21	25	12.8
20	7	2.8

TABLE 2. The Distributions and Cumulative Frequencies (in per cent) of the Ages of the 118 Pilots on Combat Duty and the 132 Pilots on Scout and Patrol Duty.

Age	Combat Duty		Scout and Patrol Duty	
	f	cum %	f %	cum %
30	1	100.0	3	100.0
29	2	99.2	3	97.7
28	9	97.5	10	95.5
27	8	89.8	6	87.9
26	11	83.0	12	83.4
25	14	73.8	8	74.2
24	26	61.8	21	68.2
23	21	39.8	28	52.3
22	14	22.0	21	31.0
21	9	10.2	16	15.2
20	3	2.5	4	3.0

TABLE 3. The Distribution and Cumulative Frequency (in per cent) of the Number of Flight Hours Logged by the Subjects. N = 250.

Number of Hours	Number of Pilots	Cumulative Per Cent
4,000	1	100.0
3,500	1	99.6
3,000	7	99.2
2,500	14	96.4
2,000	24	90.8
1,500	85	81.2
1,000	91	47.2
500	27	10.8

TABLE 4. The Distributions and Cumulative Frequencies (in per cent) of the Number of Flying Hours for 104[1] pilots on Combat Duty and 132 Pilots on Scout and Patrol Duty.

Flying Hours	Combat Duty		Scout & Patrol Duty	
	f	cum %	f	cum %
4,000	1	100.0		
3,500	1	99.0		
3,000	2	98.0	4	100.0
2,500	4	96.2	8	97.0
2,000	6	92.4	16	91.0
1,500	55	86.5	23	78.8
1,000	34	33.6	55	61.4
500	1	1.0	26	19.7

1 The records of 14 Combat Pilots were ambiguous, hence dropped.

TABLE 5. The Tabulation of the Type of Duty, Type of Plane Flown, and Number of Tours of Duty for the Subjects. N = 250.

Type of Plane Flown	Number of Tours of Duty		
	1	2	3
COMBAT DUTY			
Fighter, Dive or Torpedo Bomber	70	35	1
Heavy Land Bomber	4		
Medium Land Bomber	4		
Medium Seaplane Bomber	2		
Mixed Flights		2	
Totals (N = 118)	80	37	1
SCOUT AND PATROL DUTY			
Observation Planes	6	2	
Scout and Torpedo Bomber	11	1	
Heavy Land Bomber	9		
Medium Land Bomber	51	3	
Heavy Seaplane Bomber	7	2	
Medium Seaplane Bomber	5	1	
Naval Air Transport	6		
Ferrying all types	18		
Mixed Flights	5	16	2
Totals (N = 145)	118	25	2
ADMINISTRATIVE DUTY			
Flight Instructor	15	1	
Executive Officer, CV		1	
Other		2	
Totals (N = 19)	15	4	

TABLE 6. The Distribution and Cumulative Frequency (in per cent) of the Number of Months of Combat Duty Served by 118 of the Subjects.

Number of Months	Number of Pilots	Cumulative Per Cent
Over 34	1	100.0
33 - 34	1	99.1
31 - 32	3	98.2
29 - 30	0	95.8
27 - 28	1	95.8
25 - 26	0	95.0
23 - 24	2	95.0
21 - 22	5	93.3
19 - 20	5	89.0
17 - 18	6	84.7
15 - 16	8	79.6
13 - 14	17	72.8
11 - 12	17	58.4
9 - 10	24	44.0
7 - 8	17	23.7
6 or less	11	9.3

TABLE 7. The Distribution and Cumulative Frequency (in per cent) of the Number of Months Served on Scout and Patrol Duty by 145 Subjects.*

Number of Months	Number of Pilots	Cumulative Per Cent
Over 41	1	100.0
39 - 41	3	99.3
36 - 38	6	97.2
33 - 35	3	93.0
30 - 32	4	91.0
27 - 29	1	88.3
24 - 26	4	87.5
21 - 23	14	84.7
18 - 20	18	75.1
15 - 17	16	62.7
12 - 14	8	51.7
9 - 11	12	46.2
6 - 8	16	38.0
3 - 5	39	26.9

* Including 13 pilots who had combat duty also.

TABLE 8. The Distribution and Cumulative Frequency (in per cent) of the Number of Combat Sorties Made by 118 Subjects Who Served on Combat Duty.

Number of Sorties	Number of Pilots	Cumulative Per Cent
150	3	100.0
140	0	97.4
130	2	97.4
120	2	95.7
110	2	94.0
100	8	92.4
90	4	85.6
80	3	82.2
70	8	79.6
60	16	72.8
50	18	59.4
40	14	44.1
30	22	32.2
20	9	13.6
10	5	5.9
Not noted	2	1.7

TABLE 9. Summary of Data of Clinical Ophthalmic Examinations, Showing the Mean, Sigma and Fifth Percentile Score for each Test. N = 250, except when Otherwise Indicated.

Visual Function	Mean	Sigma	5 Percentile Score[1]
Visual Acuity - Both	14.70[2]	1.99[2]	13[2]
Visual Acuity - Right	13.96[2]	2.16[2]	10[2]
Visual Acuity - Left	13.52[2]	2.32[2]	10[2]
Near Vision - Both	.53[3]	.67[3]	20/16
Near Vision - Right	.81[3]	.81[3]	20/16
Near Vision - Left	.81[3]	.88[3]	20/16
Far Vertical Phoria	.13 $^{\Delta}$[4]LH	.30$^{\Delta}$[4]	.6$^{\Delta}$[4]RorLH
Near Vertical Phoria	.24$^{\Delta}$ LH	.55$^{\Delta}$	1.0$^{\Delta}$Ror LH
Far Lateral Phoria	.36$^{\Delta}$ESO	2.32$^{\Delta}$	4.0$^{\Delta}$ESOorEKO
Near Lateral Phoria	6.84$^{\Delta}$EXO	5.20$^{\Delta}$	5$^{\Delta}$ESO-18$^{\Delta}$EXO
Positive Vertical Divergence	1.47$^{\Delta}$	.55$^{\Delta}$	0.4$^{\Delta}$
Negative Vertical Divergence	1.73$^{\Delta}$	.57$^{\Delta}$	0.8$^{\Delta}$
Adduction	18.4$^{\Delta}$	16.7$^{\Delta}$	0.9$^{\Delta}$
Abduction	3.84$^{\Delta}$	2.13$^{\Delta}$	-1.5$^{\Delta}$
Positive Fusional Reserve	22.63$^{\Delta}$	15.5$^{\Delta}$	4.0$^{\Delta}$
Negative Fusional Reserve	17.84$^{\Delta}$	5.72$^{\Delta}$	8.4$^{\Delta}$
PcB of Convergence	60.42m/m	21.65m/m	101m/m
Angle of Convergence	58.30°	14.92°	30°
Difference in Accommodation for Right Eye	.41 D[5]	1.58 D	+2.5D to -2.5D
Difference in Accommodation for Left Eye	.43 D	1.53 D	+2.5D to -2.5D

TABLE 9. Summary of Data of Clinical Ophthalmic Examinations, Showing the Mean, Sigma and Fifth Percentile Score for each Test. N = 250, except when Otherwise Indicated. (Cont.)

Visual Function	Mean	Sigma	5 Percentile Score[1]
Howard-Dolman	20.24m/m	10.6m/m	35m/m
Stereo-Vertical (N = 130)	50[6]	8.9[6]	38[6]
Ortho-Rater Depth	6.86[7]	2.29[7]	3[7]
Verhoeff (N = 122)	8/8 @ 1-1/2M[8]	0.6M[8]	8/8 @ 1M[8]
Aniseikonia, X90 (N = 127)	.53%	1.03%	1.25%
Aniseikonia, X180 (N = 127)	.23%	.35%	.90%
Aniseikonia, Cycle (N = 127)	0.0	<.2°	<.2°
Refraction; Vertical Meridian, Right Eye	+0.37 D	0.25 D	-0.25D
Refraction; Horizontal Meridian; Right Eye	+0.25 D	0.37 D	-0.50 D
Refraction; Vertical Meridian, Left Eye	+0.37 D	0.25 D	-0.25 D
Refraction; Horizontal Meridian, Left Eye	+0.25 D	0.37 D	-0.62 D

[1] The subjects of this investigation were selected originally with better than average visual functions. The cut-off score at the 5th percentile level has been adopted so as to include the greatest proportion of these visually efficient subjects and to eliminate the lower end of this distribution where errors of measurement are more likely to occur.

[2] Arbitrary scores which correspond to the Ortho-Rater Scale Units.

[3] Decimal notation.

[4] Symbol delta (Δ) indicates prism diopters.

[5] D indicates diopters (reciprocal of focal length).

[6] In terms of standard scores established for this test.

[7] Ortho-Rater score units.

[8] Verhoeff established 8 out of 8 correct responses as his criterion of passing.

diopters of esophoria or exophoria. The standard error of the distribution is 2.32 prism diopters. For near vision, however, the mean is 6.84 prism diopters of exophoria. This is a normal or expected finding because of the lateral separation of the eyes. In clinical practice it is assumed that 4 to 6 prism diopters of exophoria is entirely normal, and that 2 to 8 prism diopters of exophoria includes the range of normal variability and probable error of measurement. It is emphasized that the standard error of the distribution of this group of subjects is large, 5.20 prism diopters, and that the range including 95 per cent of the subjects extends from 5 prism diopters of esophoria to 18 prism diopters of exophoria. This spread of scores would seem to indicate that the lateral phoria at near vision is of slight importance for a task which involves distant vision most of the time.

The measurement of positive and negative vertical divergence was conducted for distant vision only. Considering the mean of 0.13 prism diopters of left hyperphoria, these measures of vertical fusional amplitude are symmetrical. The spread of the scores and the 5 percentile scores are very low. Apparently the absence of clinical degrees of hyperphoria obviates any necessity for strong compensatory innervations.

The mean score of adduction is below the clinical standard usually considered to be normal. These subjects show a mean of 18.4 prism diopters whereas the normal expected finding is 24 prism diopters. In addition the standard error of the distribution is extremely large, 16.7 prism diopters, indicating great variability in convergence innervation for distant vision. The 5 percentile score is approximately 1 prism diopter. Apparently this function has little significance for aviation.

The mean score of abduction is much below the clinical standard usually considered to be normal. This mean is 3.84 prism diopters whereas the expected value for normal subjects is 8 prism diopters. The standard error of the distribution is large, also, and more than 5 per cent of the subjects were unable to fuse the targets at the zero position of the measuring prisms.

For near vision, the mean of the positive fusional reserve (convergence innervation) is slightly below the expected value but the standard error of the distribution is very large and the 5 percentile score is very low. On the other hand the negative fusional reserve is more nearly at the expected values. The 5 percentile score, however, is about one-half the recommended value for a cut-off score in a study conducted at Randolph Field.

The measurement of the near point of convergence, using either the PcB value which includes a constant factor added to take the center of rotation of the eyes into account, or the angle of convergence, which takes this factor and the interpupillary distance into account, does not produce any significant findings. The mean value of either measure is much below the present standards for aviation, the standard errors of the distribution are very large, and the 5 percentile scores are well beyond the present limits. It seems obvious that the convergence of the eyes bears little relationship to performance in aviation.

The mean difference in accommodation as measured and that expected according to the age scales is slightly less than 0.50 diopters for each eye, with a standard error of the distribution of slightly more than 1.50 diopters. The range including 95 per cent of the pilot population extends from 2.50 diopters below the expected to 2.50 diopters above. This shows a wide individual

variability with no tendency toward better than the expected accommodation.

On the Howard-Dolman test the mean score is about 20 mm with a standard error of the distribution of 10.6 mm. This indicates that the scores on this device are not exceptionally high in spite of much practice with it, and that the passing score of 30 mm. is probably too severe. It is noted that the 95 per cent percentile score is 35 mm. showing that some of the subjects fail the test even at this cut-off score. It should be noted, however, that using Dr. Howard's passing score of 11 seconds of arc, those with interpupillary distances of 38 mm or less should be allowed to score 35 mm. instead of 30 mm.

The Stereo-Vertical Test, which was developed for the selection of stereoscopic rangefinder operators, was administered to only 130 of the subjects because it was not possible to obtain the instrument from the Army until the experiment was one-half done. The mean score for these subjects is the same as the mean score for a normal population, namely 50. The standard error of the distribution is 8.9 as compared with 10.0 for the normal population. The passing score for rangefinder operators was established and validated at 58 whereas the 5 percentile score for the pilot population is 38. This shows that the pilot population does not differ greatly from a normal military population of the same age group having 20/20 or better vision. In other words, the pilots do not present an exceptional degree of stereoscopic vision as measured by this test.

The mean score on the Ortho-Rater test of depth perception is 6.86 with a standard error of the distribution of 2.29 scale units. Although this mean score is above that established for rangefinder operators, 5.0, the spread of ability is wide and the 5 percentile score is at 3.0. Again it is shown that the stereopsis of the pilot population is not unusually high in quality.

On the Verhoeff Test of Stereopsis the persons with exceptional depth perception pass the test easily at 2 meters. It is noted that these subjects have a mean score estimated at 1.5 meters, with a standard error of the distribution of 0.6 meters. About 95 per cent of the subjects pass the test satisfactorily at 1 meter. Dr. Verhoeff considers this an average score, indicating the presence of binocular vision and stereopsis, but not an exceptional degree of the latter.

Although only 127 subjects were measured for aniseikonia, the mean score is 0.53 per cent difference in the size of the ocular images in the horizontal meridian with a standard error of the distribution of 1.03 percent. The table shows further that 95 per cent of the subjects present an aniseikonia in this meridian which is average and below that which is considered to be significant clinically in the absence of symptoms of ocular discomfort. The findings in the vertical meridian are considerably less and have no clinical significance. The aniseikonia of the socalled "cycle" type is both infrequent and less than that considered to be significant clinically.

The errors of refraction, treated by meridians for each eye, show a mean of 0.25 to 0.37 diopters of hyperopia, with a standard error of the distribution of the same magnitude, and a 5 percentile score of 0.25 to 0.50 diopters of myopia. This shows that the subjects present very low errors of refraction, chiefly hyperopic in nature, and that some of the subjects even present a slight myopia in at least one meridian without any serious reduction of visual acuity as shown by the first items in Table 9.

TABLE 10. The Distributions and Cumulative Frequencies (in per cent) of the Scores of Visual Acuity on the Clinical Tests for Both Eyes, Right and Left Eyes. N = 250.

Acuity Score	BOTH EYES		RIGHT EYE		LEFT EYE	
	f	cum %	f	cum %	f	cum %
17	84	100.0	51	100.0	42	100.0
15	65	66.4	63	79.6	48	83.2
13	87	40.4	105	54.4	115	64.0
11	10	5.6	15	12.4	24	18.0
10	2	1.6	13	6.4	15	8.4
9	1	0.8	1	1.2	1	2.4
8		0.4	1	0.8		2.0
7		0.4		0.4	1	2.0
6	1	0.4		0.4	1	1.6
5				0.4	2	1.2
4				0.4	1	0.4
3				0.4		
2			1	0.4		

TABLE 11. The Distributions and Cumulative Frequencies (in per cent) of the Scores on Visual Acuity for the Right and Left Eyes (combined) for 118 Pilots on Combat Duty and 132 Pilots on Scout and Patrol Duty.

Acuity Score	Combat Duty		Scout & Patrol Duty	
	f	cum o/o	f	cum o/o
17	45	100.0	48	100.0
15	50	81.0	61	81.8
13	102	39.7	118	58.7
11	20	16.5	19	14.0
10	15	8.0	13	6.8
9			2	1.9
8			1	1.1
7	1	1.7		
6	1	1.3		
5	1	0.8	1	0.8
4			1	0.4
3				
2	1	0.4		

TABLE 12. The Distributions and Cumulative Frequencies (in per cent) of the Scores of Near Vision on the Clinical Tests for Both Eyes, Right and Left Eyes. N = 250.

Acuity Score	BOTH EYES		RIGHT EYE		LEFT EYE	
	f	cum o/o	f	cum o/o	f	cum o/o
20/13	142	100.0	102	100.0	104	100.0
20/16	85	43.2	102	59.2	105	58.4
20/20	22	9.2	39	18.4	31	16.4
20/25	1	0.4	6	2.8	7	4.0
20/30			1	0.4	1	1.2
20/40					2	0.8

Distributions of Scores on the Clinical Tests:

The distributions, from which the summary data presented in Table 9 are obtained, are presented in the tables which follow. These tables show the complete distribution of scores and the cumulative frequency at each score level from low to high, enabling the reader to visualize the concentration or spread of scores for the various tests.

Table 10 shows the distributions and cumulative frequencies of scores of visual acuity for both eyes, right and left eyes for all of the subjects. See Figures 5, 6 and 7. Very few subjects present an acuity of less than 20/20 (10 on the arbitrary scale), with more than 80 per cent scoring 20/15 or better (13 or better on the arbitrary scale).

In order to determine whether the type of duty, combat or patrol, was related to acuity of vision, Table 11 is presented. The distributions of scores of acuity for the right and left eyes are combined. Practically no difference is evident between these two groups.

For near vision the distributions and cumulative frequencies of scores are shown in Table 12. It is evident that almost all of the subjects score 20/20 or better while more than 80 per cent of them score 20/16 or better. Again, the scores are higher for both eyes together than for either eye separately, a common clinical finding.

The errors of refraction presented by meridians for each eye are shown in Table 13 in distributions and cumulative frequencies. It can be seen that about 10 per cent of the subjects are myopic in at least one meridian and that not over 5 per cent are hyperopic more than one diopter. With three exceptions, the myopia is less than one diopter and most of the myopic cases are less than 0.75 diopter. It is evident, as is well known clinically, that a slight myopia in one meridian may not have a deleterious effect upon the visual acuity.

In order to consider the spherical refractive error without reference to the astigmatic error, the raw data were redistributed accordingto the refractive error of the least myopic or greatest hyperopic meridian. These distributions and cumulative frequencies are presented in Table 14 and are arranged according to Combat and Patrol duty of the subjects. There is no great change in the distributions as compared with those of the separate meridians, and the refractive errors of the Combat pilots are very similar to those of the Patrol pilots. Figures 8 and 9 illustrate these distributions for the total population studied.

For distant vision all of the subjects present vertical phorias within the service limit of 1.0 prism diopter and most of them present vertical phorias of 0.6 prism diopters or less. See Table 15 and Figure 10. The group shows a slight trend toward left hyperphoria but this may be attributable to a calibration error in the Steven's Phorometer or to the method of measurement. The latter seems more likely because of the extreme sensitivity and persistence of the vertical fusional innervations. This table presents also the distributions and cumulative frequencies of the scores of vertical phoria for near vision. See Figure 11. There is a greater spread of scores, all of them falling within 2.0 prism diopters and 95 per cent within 1.5 prism diopters.

The scores of far lateral phoria all fall within 6 prism diopters of esophoria or exophoria and approximately 95 per cent fall within 4 prism diopters. For near vision, however, the spread of scores is very great, ranging from 8 prism diopters of esophoria to 18 prism diopters of exophoria. It is apparent that the distant phoria of these subjects is well within normal limits, comparable to a military population selected at random in which 98 per cent of the men present phorias between 8 prism diopters of esophoria and exophoria. The lateral phoria at near vision, on the other hand, varies greatly and, apparently, has no significance relative to Naval aviation. Refer to Table 16 and Figures 12 and 13.

The measures of convergence for both distant and near vision are scattered over a wide range as shown in Table 17 and in Figures 14 and 15. For distant vision, over one-half of the subjects demonstrate 12 prism diopters or less and three quarters of the subjects are within the 24 prism diopter "expected" limits. For near vision, more than one-half of the subjects demonstrate 20 prism diopters or less of positive fusional reserve and only 63.6 per cent of them are within the normal "expected" range.

Thus, for both conditions of testing, two-thirds to three-fourths of the subjects are within the expected normal limits and the balance range up to the limit of the testing equipment, or 60 prism diopters. On the other hand, it is important to note that one-third to one-half of the subjects are considerably below or at about one-half the normal "expected" limits.

The measures of divergence for distant vision are within normal limits, but the majority of the cases, 64 percent, present only about one-half of the "expected" degree of abduction. See Table 18 and Figures 16 and 17. Similarly, for near vision, the measures of negative fusional reserve are within the normal limits, but only about 50 per cent of the subjects meet the minimum requirement suggested by Scobee.

In Table 19 the distributions of the measures of vertical divergence are presented. While the expected vertical divergence is 3.0 prism diopters, most of the subjects present 2.0 prism diopters or less, and one-third to one-half present only 1.0 prism diopters. Although not "expected" in the clinical sense of the term, it seems logical to find low compensatory innervations in the absence of significant degrees of vertical phoria. See Table 15.

The present requirement for amplitude of accommodation or focussing power is set at 3.0 diopters from the normal according to age, after Duane's Tables. In Table 20 it is evident that these subjects present a wide range of accommodative amplitude. See Figure 18 for the distribution of differences for the left eye only. About one-fifth of them are 1.00 diopter or more below the expected and over one-fourth of them are 1.00 diopter or more above the expected amount relative to their age. None of them are more than 3.00 diopters below and only 2.4 per cent are more than 2.40 diopters below the normal. Figure 19 presents the frequency distribution of the measures of accommodation for the right eye only.

In the computation of the angle of convergence it is necessary to know the interpupillary distance of the subject. The distribution of these measures is shown in Table 21 and Figure 20. A wide range is presented, with the majority of the cases falling between 60 and 70 millimeters. A comparison with 59 enlisted men selected at random and measured with the same type of instrument at

TABLE 13. The Distributions and Cumulative Frequencies (in per cent) of the Refractive Errors by Meridians for the Right and Left Eyes of the Subjects Measured by the Standard Subjective Technique without Cycloplegia. N = 250.

Correction in Diopters	Right Eye				Left Eye			
	Vertical		Horizontal		Vertical		Horizontal	
	f	cum o/o	f	cum o/o	f	cum o/o	f	cum o/o
+ 2.00			1	100.0				
+1.75				99.6			2	100.0
+1.50	1	100.0	4	99.6	3	100.0	5	99.2
+1.25	12	99.6	7	98.0	7	98.8	2	97.2
+1.00	18	94.8	13	95.2	17	96.0	21	96.4
+0.75	49	87.6	39	90.0	49	89.2	41	88.0
+0.50	76	68.0	60	74.4	76	69.6	59	71.6
+0.25	50	37.6	52	50.4	54	39.2	59	48.0
0.00	28	17.6	45	29.6	30	17.6	36	24.4
-0.25	11	6.4	16	11.6	8	5.6	16	10.0
-0.50	4	2.0	10	5.2	4	2.4	5	3.6
-0.75		0.4	2	1.2		0.8	4	1.6
-1.00		0.4	1	0.4	2	0.8		
-1.25	1	0.4						

TABLE 14. The Distributions and Cumulative Frequencies (in per cent) of the Refractive Errors, using the least Myopic or highest Hyperopic Meridian for the Right and Left Eyes arranged according to Combat and Patrol Duty. N = 118 Combat Pilots, 132 Patrol Pilots.

Correction in Diopters	Right Eye				Left Eye			
	Combat		Patrol		Combat		Patrol	
	f	cum o/o	f	cum o/o	f	cum o/o	f	cum o/o
+2.00	1	100.0						
+1.75					1	100.0	1	100.0
+1.50	3	99.2	1	100.0	3	99.2	3	99.2
+1.25	7	96.6	3	99.2	3	96.6	1	97.0
+1.00	7	90.7	18	97.0	11	94.1	16	96.2
+0.75	30	84.7	36	83.3	30	84.7	35	84.1
+0.50	35	59.3	35	56.1	33	59.3	45	57.6
+0.25	23	29.7	27	30.3	27	31.4	20	23.5
0.00	3	10.2	2	9.1	2	8.5	2	8.3
-0.25	4	7.6	7	7.6	6	6.8	5	6.8
-0.50	4	4.2	2	2.3	1	1.7	3	3.0
-0.75		0.8	1	0.8	1	0.8	1	0.8
-1.00	1	0.8						

TABLE 15. The Distribution and Cumulative Frequencies (in per cent) of the Vertical Phoria Presented by the Subjects for Distant and Near Vision. N = 250.

Vertical Phoria Prism Diopters	Distant Vision		Near Vision	
	f	cum o/o	f	cum o/o
1.7 - 1.8 R Hyper			1	100.0
1.5 - 1.6				99.6
1.3 - 1.4			1	99.6
1.1 - 1.2			1	99.2
0.9 - 1.0	2	100.0	3	98.8
0.7 - 0.8		99.2	3	97.6
0.5 - 0.6	5	99.2	7	96.4
0.3 - 0.4	9	97.2	15	93.6
0.1 - 0.2	19	93.6	15	87.6
Orthophoria	95	86.0	66	81.6
0.1 - 0.2 L Hyper	41	48.0	32	55.2
0.3 - 0.4	55	31.6	36	42.4
0.5 - 0.6	20	9.6	30	28.0
0.7 - 0.8	4	1.6	18	16.0
0.9 - 1.0			4	8.8
1.1 - 1.2			6	7.2
1.3 - 1.4			4	4.8
1.5 - 1.6			5	3.2
1.7 - 1.8			3	1.2

TABLE 16. The Distributions and Cumulative Frequencies (in per cent) of the Lateral Phoria Presented by the Subjects for Distant and Near Vision. N = 250.

Lateral Phoria Prism Diopters	Distant Vision		Near Vision	
	f	cum o/o	f	cum o/o
17 - 18 EXO			11	100.0
15 - 16			6	95.6
13 - 14			14	93.2
11 - 12			13	87.6
9 - 10			37	82.4
7 - 8			38	67.6
5 - 6	3	100.0	44	52.4
3- 4	12	98.8	38	34.8
1 - 2	56	94.0	24	19.6
Orthophoria	80	71.6	6	10.0
1 - 2 ESO	69	39.6	10	7.6
3 - 4	25	12.0	4	3.6
5 - 6	5	2.0	2	2.0
7 - 8			3	1.2

TABLE 17. The Distributions and Cumulative Frequencies (in per cent) of the Measures of Adduction for Distant Vision and Positive Fusional Reserve for Near Vision presented by the Subjects. N = 250.

Adduction or P.F.R. Prism Diopters	Distant Vision f	Distant Vision cum o/o	Near Vision f	Near Vision cum o/o
57 - 60	10	100.0	6	100.0
53 - 56	9	96.0	4	97.6
49 - 52	9	92.4	10	96.0
45 - 48	6	88.8	10	92.0
41 - 44	3	86.4	14	88.0
37 - 40	9	85.2	14	82.4
33 - 36	5	81.6	9	76.8
29 - 32	5	79.6	11	73.2
25 - 28	6	77.6	13	68.8
21 - 24	12	75.2	28	63.6
17 - 20	13	70.4	27	52.4
13 - 16	24	65.2	20	41.6
9 - 12	42	55.6	27	33.6
5 - 8	71	38.8	41	22.8
1 - 4	26	10.4	14	6.4
0 - (-3)				0.8
(-4) - (-7)			2	0.8

[redacted]

TABLE 18. The Distributions and Cumulative Frequencies (in per cent) of the Measures of Abduction for Distant Vision and Negative Fusional Reserve for Near Vision Presented by the Subjects. N = 250.

Abduction Prism Diopters	Distant Vision		Negative Fusional Reserve	Near Vision	
	f	cum o/o	Prism Diopters	f	cum o/o
9 - 10	3	100.0	+24	29	100.0
7 - 8	11	98.8	22 - 24	49	88.4
5 - 6	76	94.4	19 - 21	39	68.8
3 - 4	119	64.0	16 - 18	63	53.2
1 - 2	30	16.4	13 - 15	19	28.0
0	0	4.4	10 - 12	30	20.4
(-1)-(1-2)	9	4.4	7 - 9	13	8.4
(-3)-(-4)	2	0.8	4 - 6	7	3.2
			1 - 3		0.4
			0 -(-2)		0.4
			(-3)-(-5)	1	0.4

[redacted]

TABLE 19. The Distributions and Cumulative Frequencies (in per cent) of the Measures of Positive and Negative Vertical Divergence Presented by the Subjects for Distant Vision. N = 250.

Vertical Divergence Prism Diopters	Positive		Negative	
	f	cum o/o	f	cum o/o
4	1	100.0	2	100.0
3	4	99.6	9	99.2
2	106	98.0	160	95.6
1	139	55.6	78	31.6
0			1	0.4

TABLE 20. The Distributions and Cumulative Frequencies (in per cent) of the Difference in Accommodation Relative to the Standard Norms according to the Ages of the Subjects, for the Right and Left Eyes. N = 250.

Difference in Accommodation Diopters	Right Eye f	Right Eye cum o/o	Left Eye f	Left Eye cum o/o
More than 2.4 above normal	31	100.0	34	100.0
2.2 - 2.4	6	87.6	6	86.4
1.9 - 2.1	13	85.2	13	84.0
1.6 - 1.8	5	80.0	6	78.8
1.3 - 1.5	14	78.0	15	76.4
1.0 - 1.2	22	72.4	20	70.4
0.7 - 0.9	19	63.6	20	62.4
0.4 - 0.6	19	56.0	20	54.4
0.1 - 0.3	10	48.4	9	46.4
Normal	18	44.4	15	42.8
0.1 - 0.3 below normal	18	37.2	14	36.8
0.4 - 0.6	17	30.0	16	31.2
0.7 - 0.9	8	23.2	8	24.8
1.0 - 1.2	17	20.0	17	21.6
1.3 - 1.5	5	13.2	7	14.8
1.6 - 1.8	7	11.2	9	12.0
1.9 - 2.1	9	8.4	9	8.4
2.2 - 2.4	6	4.8	6	4.8
More than 2.4 below normal	6	2.4	6	2.4

TABLE 21. The Distribution of Measures of Interpupillary Distance for which the Mean is 65.11 millimeters, Standard Error is 2.92 millimeters, and N is 250.

Interpupillary Distance	Number of Pilots
74 m/m	1
73	1
72	5
71	4
70	7
69	14
68	14
67	23
66	37
65	41
64	34
63	27
62	16
61	11
60	9
59	3
58	2.
57	1

TABLE 22. Comparison of Measurements of Interpupillary Distance between 250 Naval Aviators and 59 Enlisted Students in Fire Control[1].

Subjects	Mean	Standard Error
250 Naval Aviators	65.42 m/m	2.70 m/m
59 Enlisted Men	65.45 m/m	2.22 m/m

[1]Naval Training Schools, Fort Lauderdale, Florida, from Report No. 2, Project N-114, OSRD Report No. 3475, University of Wisconsin, 29 March 1944.

TABLE 23. The Distribution and Cumulative Frequency (in per cent) of the Measures of Convergence (PcB = Near Point of Convergence + 25 m/m) Presented by the Subjects. N = 250.

PcB of Convergence Millimeters	Frequency	
	Number	Cumulative Per Cent
31 - 40	61	100.0
41 - 50	27	75.6
51 - 60	43	64.8
61 - 70	51	47.6
71 - 80	31	27.2
81 - 90	19	14.8
91 - 100	4	7.2
101 - 110	5	5.6
111 - 120	6	3.6
121 - 130	1	1.2
131 - 140		0.8
141 - 150	2	0.8

TABLE 24. The Distribution and Cumulative Frequency (in per cent) of the Measures of the Angle of Convergence Presented by the Subjects. N = 250.

Angle of Convergence	Frequency	
Degrees	Number	Cumulative Per Cent
Over 80	11	100.0
76 - 80	43	95.6
71 - 75	15	78.4
66 - 70	12	72.4
61 - 65	15	67.6
56 - 60	36	61.6
51 - 55	33	47.2
46 - 50	30	34.0
41 - 45	33	22.0
36 - 40	10	8.8
31 - 35	8	4.8
26 - 30	4	1.6

the Naval Training School, Fort Lauderdale, Florida, is presented in Table 22. It is noted that the means are practically the same. Apparently there is no tendency for aviators to have wider interpupillary distance than a group unselected relative to this factor.

The near point of convergence is measured according to standard procedures and the PcB of convergence is obtained by adding a constant, 25 millimeters. which relates the near point to the centers of rotation of the eyes. The distribution of these values of PcB is presented in Table 23 and Figure 21. The total range is great, but 95 per cent of the subjects are within 110 millimeters. When these values are converted to the angle of convergence, the resulting distribution is shown in Table 24 and Figure 22. Although 40 is the present minimum angle of convergence, 8.8 per cent of the subjects fall below this standard.

An estimate of the degree of aniseikonia in Naval aviation cadets was obtained in a previous study at Pensacola. Using a more reliable and valid measure of aniseikonia, 127 subjects were tested for this anomaly. This instrument presents three measures of aniseikonia, for the horizontal and vertical meridians and the so-called "cyclo" distortion. Inasmuch as 90 per cent of the subjects show no "cycle" effect, only the distributions for the horizontal and vertical meridians are presented in Table 25. It is obvious that a few subjects have aniseikonia to a degree that is considered to be significant clinically. However, over 93 per cent have 1.00 per cent or less aniseikonia, a degree which is usually tolerated without the development of symtoms. These distributions are very similar to those obtained in the previous study mentioned above, and suggest the same conclusion; i.e., the selective process based upon high visual acuity and low refractive error may eliminate most subjects having a significant degree of anisekonia.

All of the subjects were tested for aniseikonia for near vision. In Table 26 the distributions for the horizontal and vertical meridians are presented. It is noted that at least 88 per cent of the subjects show an aniseikonia of 1.00 per cent or less and that 86.4 per cent show no aniseikonic cycle distortion. As a matter of clinical interest the types of aniseikonia presented by these subjects are shown in Table 27. About one-third of the subjects present no aniseikonia. About 10 per cent of the subjects show an aniseikonia of the overall or spherical type while 25 per cent show meridional aniseikonia axis 90° and 17 per cent show meridional aniseikonia axis 180°. About 12 per cent show various combinations of crossed meridional or overall with meridional. Three per cent show a cycle distortion without any overall or meridional aniseikonia.

Depth Perception: The results of four tests of depth perception are presented in the following tables. In Table 28 the distribution and cumulative frequency of scores on the Ortho-Rater test of stereopsis are presented. See Figure 23 for the frequency distribution. It is noted that a few fail the test, 9.2 per cent pass at level 3, one-half score 7 and 42 per cent make the highest score. This suggests that a high degree of stereopsis is not characteristic of Naval aviators, as measured by this device. When the stereopsis of the Combat and Patrol pilots is compared in Table 29, the wide range of scores is noted again. However, there is a significant difference in the proportion of pilots scoring 9 on this device ($p = < .01$). Of the Patrol group 50 per cent score 9 whereas only 33 per cent of the Combat group make this score. This

TABLE 25. The Distributions and Cumulative Frequencies (in per cent) of the Degree of Horizontal and Vertical Aniseikonia* Presented by the Subjects on the Vectographic Test of Aniseikonia. N = 127.

Degree of Aniseikonia o/o Size Difference	Horizontal Meridian		Vertical Meridian	
	f	cum o/o	f	cum o/o
0.00	43	100.0	81	100.0
0.50	45	66.2	37	36.2
1.00	30	30.7	7	7.1
1.50	6	7.1	1	1.6
2.00	2	2.4	1	0.8
2.50	1	0.8		

*Inasmuch as 90 per cent of the subjects show no aniseikonic cycle distortion, the distribution is not presented.

TABLE 26. The Distributions and Cumulative Frequencies (in per cent) of the Degree of Horizontal and Vertical Aniseikonia* for Near Vision Presented by the Subjects on the Vectographic Test of Aniseikonia. N = 250.

Degree of Aniseikonia o/o Size Difference	Horizontal Meridian		Vertical Meridian	
	f	cum o/o	f	cum o/o
0.00	147	100.0	151	100.0
0.50	73	41.2	82	39.6
1.00	22	12.0	15	6.8
1.50	6	3.2	1	0.8
2.00	2	0.8	1	0.4

*Inasmuch as 86.4 per cent of the subjects show no aniseikonic cycle distortion, the distribution is not presented.

TABLE 27. Showing the Number and Frequency of Subjects Presenting Aniseikonia Arranged According to Types of Aniseikonia as Measured with the Vectographic Space Eikonometer for Near Vision. N. = 250.

Type of Aniseikonia	Number of Subjects	Per Cent
No Aniseikomia	82	32.8
Overall	24	9.6
Meridional (axis 90°)	63	25.2
Meridional (axis 180°)	42	16.8
Crossed Meridional	15	6.0
Overall with axis 90°	13	5.2
Overall with axis 180°	4	1.6
Cycle distortion only	7	2.8
Totals	250	100.0

TABLE 28. The Distribution and Cumulative Frequency (in per cent) of the Scores on the Ortho-Rater Test of Depth Perception Made by the Subjects. N = 250.

Ortho-Rater Score	Number of Pilots	Cumulative Per Cent
9	105	100.0
8	15	58.0
7	24	52.0
6	35	42.4
5	33	28.4
4	15	15.2
3	11	9.2
2	6	4.8
1	3	2.4
0	3	1.2

TABLE 29. The Distributions and Cumulative Frequencies (in per cent) of the Scores on Depth Perception on the Ortho-Rater for 118 Pilots on Combat Duty and 132 Pilots on Scout and Patrol Duty.

Depth Score	Combat Duty		Scout & Patrol Duty	
	f	cum o/o	f	cum o/o
9	39	100.0	66	100.0
8	5	67.0	10	50.0
7	15	62.7	9	42.4
6	20	50.0	15	35.6
5	18	33.0	15	24.2
4	7	17.8	8	12.9
3	8	11.9	3	6.8
2	3	5.1	3	4.5
1	1	2.5	2	2.3
0	2	1.7	1	0.8

TABLE 30. The Distribution and Cumulative Frequency (in per cent) of the Scores on the Howard-Dolman Test of Depth Perception Made by the Subjects. N = 250.

Score m/m	Number of Pilots f	Cumulative Per Cent o/o
0 - 5	27	100.0
6 - 10	65	89.2
11 - 15	50	63.2
16 - 20	46	43.2
21 - 25	31	24.8
26 - 30	12	12.4
31 - 35	7	7.6
36 - 40	3	4.8
41 - 45	3	3.6
46 - 50	1	2.4
51 - 55	3	2.0
Over 55	2	0.8

TABLE 31. The Distributions and Cumulative Frequencies (in per cent) of the Score on the Howard-Dolman Test of Depth Perception for 118 Pilots on Combat Duty and 132 Pilots on Scout and Patrol Duty.

Depth Score Millimeters	Combat Duty		Scout & Patrol Duty	
	f	cum o/o	f	cum o/o
0 - 5	12	100.0	15	100.0
6 - 10	30	89.7	35	88.5
11 - 15	25	64.4	25	62.2
16 - 20	20	43.2	26	43.2
21 - 25	16	26.2	15	23.4
26 - 30	6	12.7	6	12.1
31 - 35	4	7.6	3	7.6
36 - 40		4.2	3	5.3
41 - 45	1	4.2	2	3.0
46 - 50	1	3.4		1.5
51 - 55	2	2.5	1	1.5
56 - 60		0.8		0.8
61 - 65	1	0.8		0.8
>65			1	0.8

TABLE 32. The Distribution and Cumulative Frequency (in per cent) of the Scores on the Stereo-Vertical Test of Depth Perception Made by the Subjects. N = 130.

Standard Score	Number of Pilots	Cumulative Per Cent
71 - 75	2	100.0
66 - 70	3	98.4
61 - 65	11	96.2
56 - 60	19	87.7
51 - 55	28	73.0
46 - 50	25	51.6
41 - 45	20	32.3
36 - 40	17	16.9
Below 36	5	3.9

TABLE 33. Comparison of Scores of Depth Perception on the Stereo-Vertical Test between 541 Enlisted Men[1] and 130 Naval Aviators, Showing the Distributions and Cumulative Frequencies (in per cent).

Depth Score	Enlisted Men		Naval Aviators	
	f	cum o/o	f	cum o/o
71 - 75	1	100.0	2	100.0
66 - 70	13	99.8	3	98.4
61 - 65	67	97.4	11	96.1
56 - 60	103	85.0	19	87.6
51 - 55	128	65.9	28	73.0
46 - 50	117	42.3	25	51.5
41 - 45	79	20.7	20	32.3
36 - 40	28	6.1	17	16.9
31 - 35	5	0.9	5	3.8

[1]All of these men had 20/20 vision or better.

is in the opposite direction which one might expect if one assumes that the fighter pilot accustomed to flying in formation needs a higher degree of depth perception, as measured by this instrument.

A wide distribution of scores on the Howard-Dolman test is shown in Table 30 and Figure 24. Only 93 per cent make passing scores in spite of considerable previous practice with this instrument. When the Combat and Patrol groups are compared in Table 31, there is no obvious or significant difference in scores on the Howard-Dolman test at any level of performance.

The Stereo-Vertical Test was used with a high degree of success in both the Army and the Navy in predicting performance with the stereoscopic rangefinder used in antiaircraft fire control. In Table 32 and Figure 25, however, the distribution of scores on this test is very wide, ranging from very poor to very good and being symmetrical relative to the median or average score. That this distribution is similar to that found in a similar population having 20/20 vision is shown in Table 33. The scores on the Stereo-Vertical Test obtained by 541 enlisted men having 20/20 vision and normal muscle balance are presented with the distribution of scores obtained by the subjects of this experiment. These enlisted men were tested at the Naval Training Center, Sampson, New York, as part of the routine procedure for the selection of candidates for the Rangefinder School at Fort Lauderdale, Florida. It is apparent that the same proportion of each group make superior scores (56-60) on this test. At all of the lower levels the proportion of aviators is higher than that of the enlisted group, indicating inferior performance of this test.

The Verhoeff Test of depth perception, as administered in this experiment, has four levels of proficiency: superior, average, inferior and fail. The distribution in Table 34 and Figure 26 shows that about one-half of these subjects make superior scores, about one-half make average scores, and only four subjects make inferior or failing scores. Thus in all four tests, there is evidence that the Aviators do not possess an unusually high degree of stereopsic, or depth perception based upon binocular parallex.

TABLE 34. The Distribution and Cumulative Frequency (in per cent) of the Scores on the Verhoeff Test of Depth Perception Made by the Subjects. N = 122.

Verhoeff Score 8/8 correct at	Number of Pilots	Cumulative Per Cent
2 meters	59	100.0
1 meter	59	51.6
0.5 meters	2	3.3
Fail 0.5 meters	2	1.6

SUMMARY

1. In order to evaluate the visual portion of the flight physical examination, 250 Naval Aviators, who were returning from combat or operational tours of duty, were given a complete eye examination, including all of the tests required for flight status and a number of other tests.

2. The subjects, ranging in age from 20 to 30 years, with a mean of 24.05 years, are about equally divided relative to combat and patrol duty. The combat pilots logged a greater number of hours of flying, but served a shorter tour of duty.

3. The pilots with combat experience flew chiefly in fighter, dive-bomber or torpedo-bomber planes. Those with patrol duty used medium land bombers for the most part, and a mixture of all other types.

4. The median number of sorties participated in by the combat pilots was approximately 50.

5. On the clinical tests, the subjects present superior scores on visual acuity, near vision, far and near vertical phoria, and aniseikonia. There are wide variations in scores on all other clinical tests. The compensatory innervations, although wide in range, tend, on the average, to be below normal. The near points of convergence and accommodation extend over wide ranges. The scores of depth perception are average to below average. The errors of refraction are low and not significant clinically. The range and mean of interpupillary distance are similar to those for a population selected at random.

6. There is a small but definite relationship between vertical phorias measured by the clinical method and the compensatory fusional innervations.

7. The compensatory innervation, termed "abduction", bears a substantial relationship to far lateral phoria measured by the clinical method.

8. There is no significant relationship between the compensatory innervation, termed "adduction", and far lateral phoria measured by the clinical method.

9. There is a small but definite relationship between the measures of near lateral phoria obtained by the clinical method and the compensatory innervations measured at the same distance.

10. The relationship between the measurement of the near point of convergence and the compensatory innervations termed "adduction" and "positive fusional reserve" is substantial.

11. The near point of convergence is not related, significantly, to any other clinical test, interpupillary distance or age.

12. Age bears no significant relationship to heterophoria, acuity or accommodation for this group of subjects.

13. Accommodation and heterophoria are not related to a significant degree.

14. Aniseikonia measured at distant vision is substantially related to the findings for near vision for these subjects measured at both distances. Prediction for the individual case is not permissible, however.

15. Although fairly reliable, the tests of depth perception are not closely related to each other. The Stereo-Vertical test, which is highly efficient in selecting stereoscopic rangefinder operators presents the lowest degrees of relationship to the other tests of depth perception.

16. The subjects of this investigation do not differ in the distribution of scores obtained on the Sterio-Vertical test from a population selected on the basis of good visual acuity (20/20 Snellen).

17. There is a small but definite relationship between visual acuity and performance on the four tests of depth perception.

18. Meridional aniseikonia bears a slight relationship to the Stereo-Vertical and Verhoeff tests of depth perception but bears no significant relationship to the Ortho-Rater and Howard-Dolman tests.

19. Age is not a factor in depth perception for the subjects of this investigation.

20. Of the 250 Naval Aviators examined, 78 were unable to pass a strict interpretation of the regulations concerning physical requirements. Of these 78 subjects, 26 failed only the red lens test; 8 failed the red lens test and one other test; 10 did not have sufficient abduction to compensate for their esophoria, and 4 of these also failed the Howard-Dolman test of depth perception; 17 failed the test of convergence and one of these failed the Howard-Dolman test; 3 were below the 3 diopter limit for accommodation; 2 had less than 15/20 vision and one of these failed the Howard-Dolman test; 2 failed the color vision test; and 10 failed only the Howard-Dolman test of depth perception.

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Discussion:

In the discussion that followed Dr. Imus' paper, Dr. Imus made the point that the fliers who returned from combat duty had much better than 20/20 visual acuity.

Wing Commander Nelson expressed agreement with Dr. Imus's findings, particularly with the validity of visual acuity measurements for predicting success in combat. He reported three cases of combat aviators with defective color vision. Since landings are made at night by means of colored signals, Commander Nelson was baffled by the ability of these fliers with defective vision to make successful landings. Interrogations of the pilots did not reveal the means by which these men were able to make successful night landings with defective color vision.

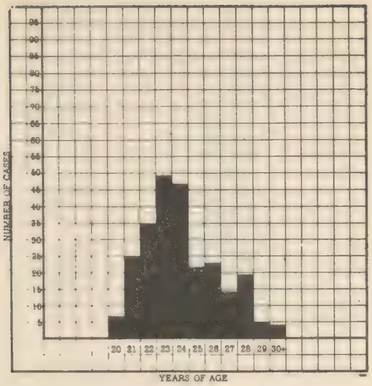

FIGURE 1: FREQUENCY DISTRIBUTION OF AGE OF SUBJECTS.

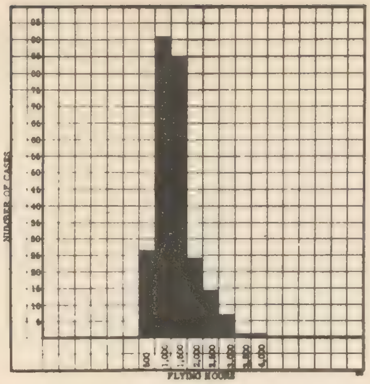

FIGURE 2: FREQUENCY DISTRIBUTION OF TOTAL OF HOURS OF FLYING.

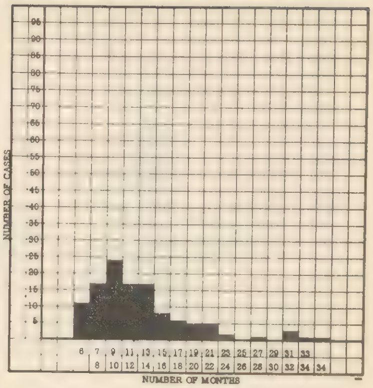

FIGURE 3: FREQUENCY DISTRIBUTION OF THE NUMBER OF MONTHS SERVED ON COMBAT DUTY. N is 118.

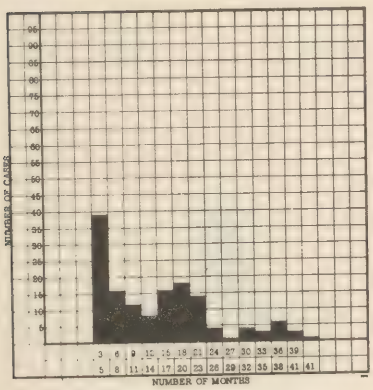

FIGURE 4: FREQUENCY DISTRIBUTION OF THE NUMBER OF MONTHS SERVED ON SCOUT AND PATROL DUTY. N is 145 (including 13 pilots who had combat duty also).

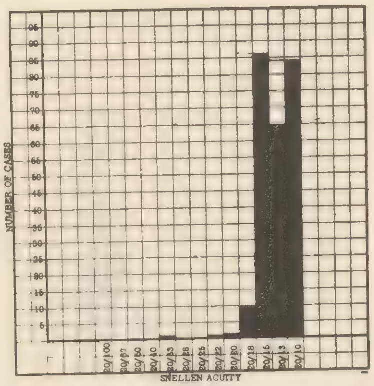

FIGURE 5: THE DISTRIBUTION OF SCORES FOR VISUAL ACUITY OF BOTH EYES BY THE CLINICAL METHOD.

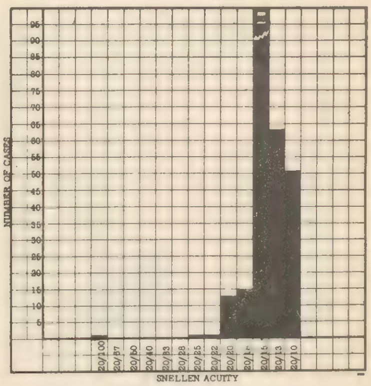

FIGURE 6: THE DISTRIBUTION OF SCORES FOR VISUAL ACUITY OF THE RIGHT EYE BY THE CLINICAL METHOD.

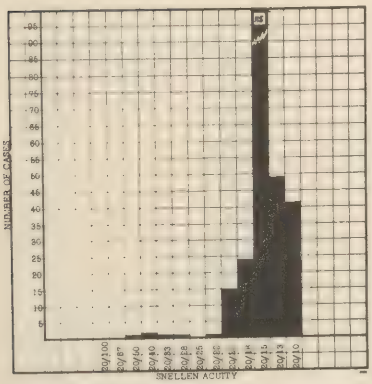

FIGURE 7: THE DISTRIBUTION OF SCORES FOR VISUAL ACUITY OF THE LEFT EYE BY THE CLINICAL METHOD.

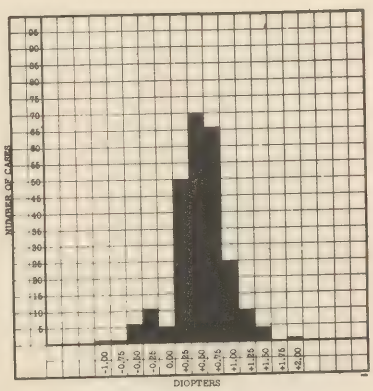

FIGURE 8: THE DISTRIBUTION OF SCORES FOR REFRACTIVE ERROR, RIGHT EYE, BY THE CLINICAL METHOD.

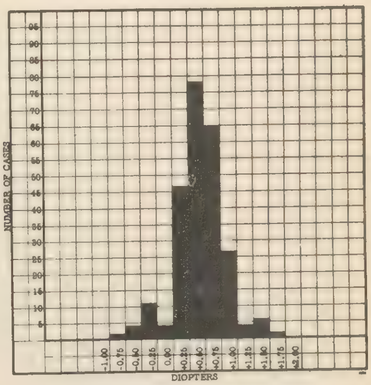

FIGURE 9: THE DISTRIBUTION OF SCORES OF REFRACTIVE ERROR, LEFT EYE, BY THE CLINICAL METHOD.

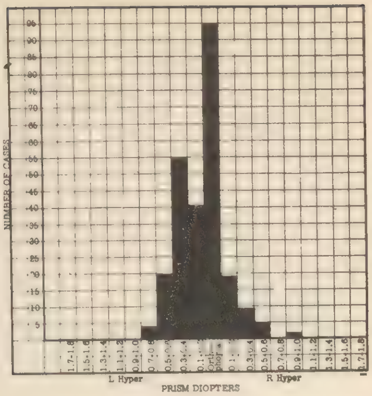

FIGURE 10: THE DISTRIBUTION OF SCORES FOR VERTICAL PHORIA, DISTANT VISION, BY THE CLINICAL METHOD.

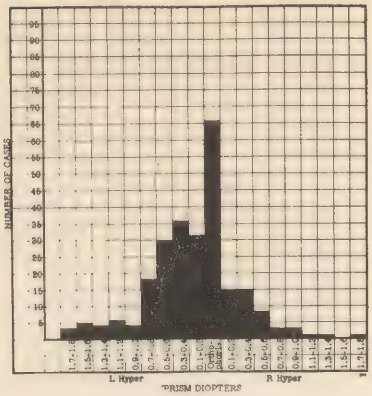

FIGURE 11: THE DISTRIBUTION OF SCORES FOR VERTICAL PHORIA, NEAR VISION, BY THE CLINICAL METHOD.

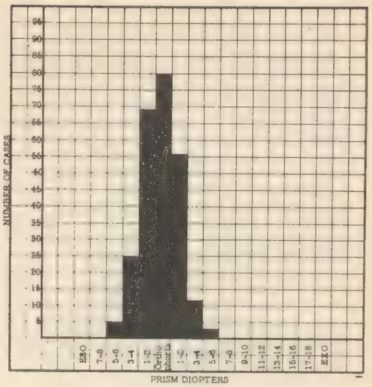

FIGURE 12: THE DISTRIBUTION OF SCORES FOR LATERAL PHORIA, DISTANT VISION, BY THE CLINICAL METHOD.

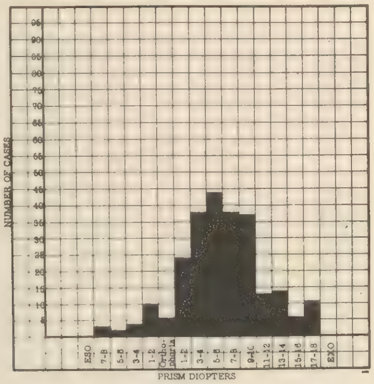

FIGURE 13: THE DISTRIBUTION OF SCORES FOR LATERAL PHORIA, NEAR VISION, BY THE CLINICAL METHOD.

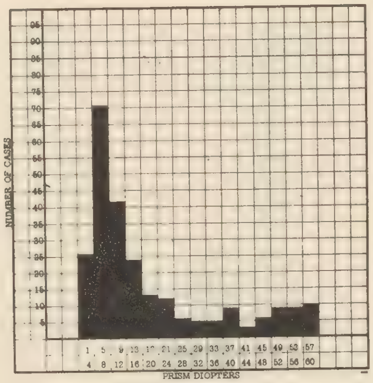

FIGURE 14: FREQUENCY DISTRIBUTION OF RAW SCORES OF ADDUCTION.

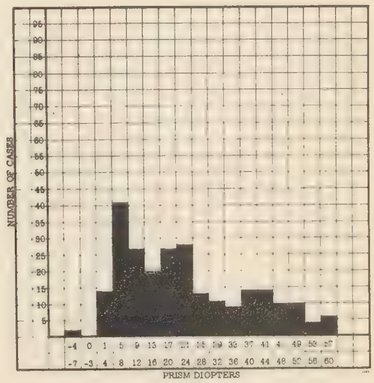

FIGURE 15: FREQUENCY DISTRIBUTION OF RAW SCORES OF POSITIVE FUSIONAL RESERVE.

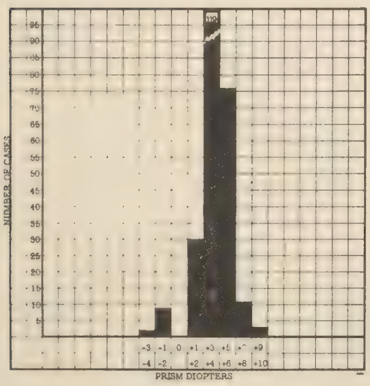

FIGURE 16: FREQUENCY DISTRIBUTION OF RAW SCORES OF ABDUCTION.

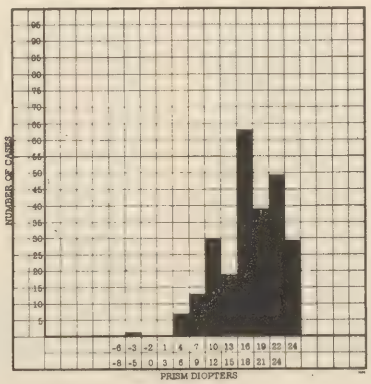

FIGURE 17: FREQUENCY DISTRIBUTION OF RAW SCORES OF NEGATIVE FUSIONAL RESERVE.

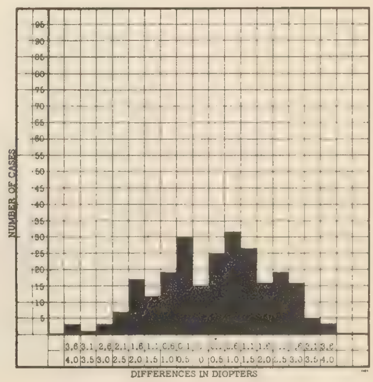

FIGURE 18: FREQUENCY DISTRIBUTION OF THE DIFFERENCES BETWEEN THE MEASURED ACCOMMODATION OF THE LEFT EYE AND THE EXPECTED VALUES ACCORDING TO AGES OF THE SUBJECTS.

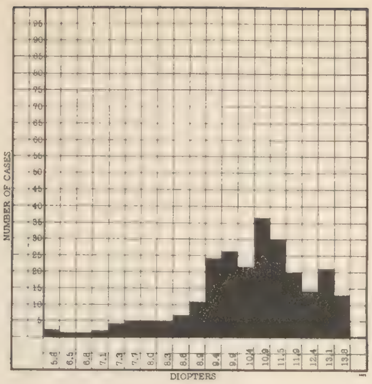

FIGURE 19: FREQUENCY DISTRIBUTION OF THE MEASURES OF ACCOMMODATION FOR THE RIGHT EYE ONLY.

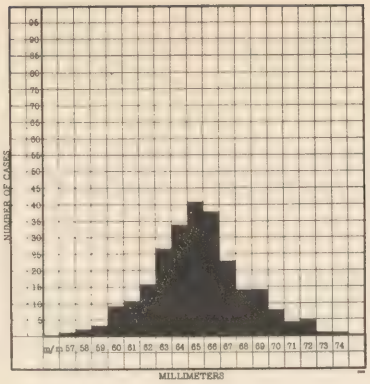

FIGURE 20: FREQUENCY DISTRIBUTION OF MEASURES OF INTERPUPILLARY DISTANCE.

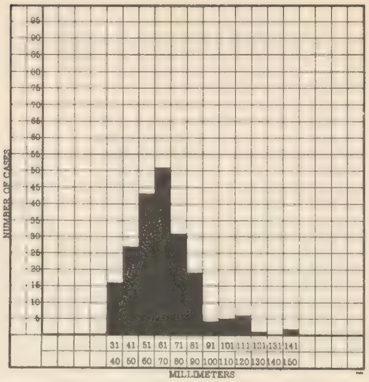

FIGURE 21: FREQUENCY DISTRIBUTION OF THE SCORES OF PcB OF CONVERGENCE.

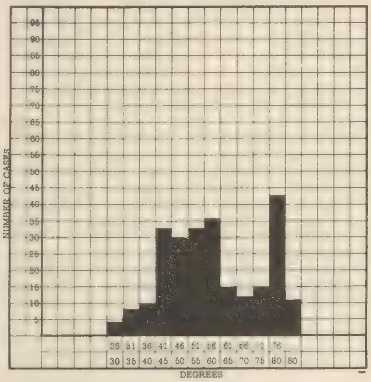

FIGURE 22: FREQUENCY DISTRIBUTION OF THE ANGLES OF CONVERGENCE.

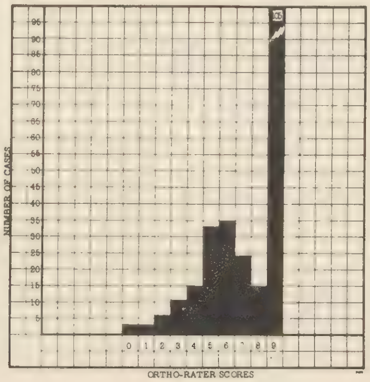

FIGURE 23: FREQUENCY DISTRIBUTION OF THE SCORES OF DEPTH PERCEPTION ON THE ORTHO-RATER.

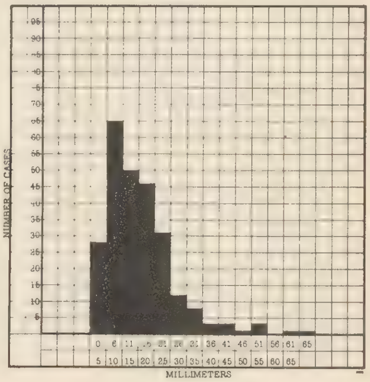

FIGURE 24: FREQUENCY DISTRIBUTION OF THE SCORES OF DEPTH PERCEPTION ON THE HOWARD-DOLMAN TEST.

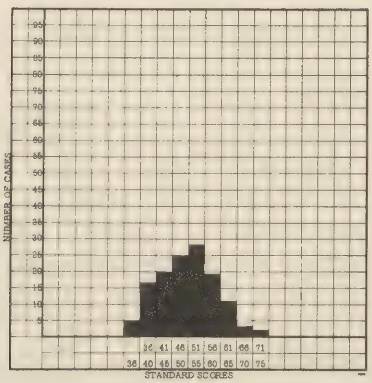

FIGURE 25: FREQUENCY DISTRIBUTION OF THE STANDARD SCORES OBTAINED ON THE STEREO-VERTICAL TEST. N is 130.

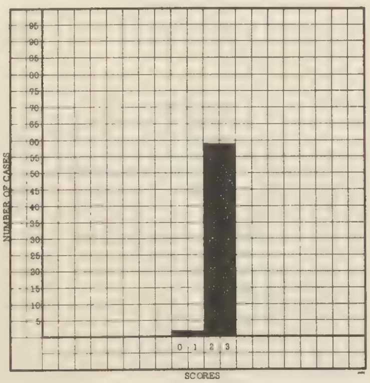

FIGURE 26: FREQUENCY DISTRIBUTION OF THE SCORES OF DEPTH PERCEPTION ON THE VERHOEFF TEST.

FURTHER REPORTS ON TESTING HETEROPHORIA

by

Richard G. Scobee, M.D., and Earl L. Green, Ph.D.

This is a preliminary report of further studies in the field of heterophoria. The work was done under the sponsorship of the Office of Naval Research as Project N6onr-202, Task Order I. Two sub-projects are being reported at this time.

PROJECT SG-102

This study is one of several concerned with the effect of variables in testing technique on the measurement of heterophoria with the Maddox rod test. The particular variable studied was that of the size of the line of light as seen through the Maddox rod in testing heterophoria at near fixation (13 inches). Since the size of the muscle light for near heterophoria testing might easily vary from one testing station to the next, any possible effect of this size difference should be determined. Two test lights were used. One was an ophthalmoscope with a May-type head removed; the other was a flashlight fitted with a solid diaphragm in which a hole 1.0 mm. in diameter had been bored. The ophthalmoscope light gave a broad line image when viewed through a Maddox rod while the 1.0 mm. light gave a narrow, sharply delimited line. All measurements of heterophoria were made at a testing distance of 13 inches. The testing technique was that described in detail in the manual entitled HETEROPHORIA TESTING approved by this committee. 32 subjects were studied.

Lateral heterophoria. The average heterophoria was -4.89 prism diopters (exophoria) when the source of the light was large (ophthalmoscope) and -4.87 prism diopters when the source of light was small (flashlight). The difference of 0.02 prism diopters is not statistically, the standard error of the difference being 0.398 prism diopters ($t = 0.05$, $df = 31$, $P > .90$).

Two tests were made of the justification for using the statistical method of comparing a mean difference with its standard error. The first of these was to see if the frequency distributions of heterophoria under the two conditions of large and small sources of light were approximately normal in form. The distributions were shown to be sufficiently symmetrical and bell-shaped to justify the assumption of normality. The second test was to see if the variances of the two distributions were the same within sampling limits. These variances were found to be 25.67 square prism diopters for the large light source and 25.72 square prism diopters for the small light source. The ratio of these two variances, $F = 1.002$, indicates they are not significantly different as judged by the method of Morgan (1939) for comparing variances of correlated series.

The heterophoria determinations under the two conditions of large and small light sources are highly correlated, $r = +0.90$. This is sufficiently high to indicate that knowledge of a heterophoria reading made under one condition will be equivalent for most practical circumstances to a heterophoria reading made under the other condition. Of the 32 subjects examined, only one had as much as 6 diopters difference, a shift from -14 prism diopters with the large light to -8 prism diopters with the small light. Two subjects had shifts

of 4 prism diopters, one from +4 to +8, the other from -6 to -10. The remaining 29 subjects gave readings with differences of 3 prism diopters or less.

Vertical heterophoria. The average heterophoria was -0.03 prism diopters with a large light source and +0.03 prism diopters with a small light source. The difference of 0.06 prism diopters is not significant when compared with its standard error of 0.12 prism diopters, ($t = 0.48$, $df = 31$, $P = .70 - .60$). The correlation coefficient was +0.85 and this is high enough to permit substitution of the large light for the small light reading or vice versa.

The same two tests for the justification of using the above test of significance were made. The distributions were approximately normal in form and the variances, 0.664 and 0.660, were homogeneous.

Table I.

Average heterophorias for 32 subjects for two sources of light.

Source of light	Lateral heterophoria (in prism diopters)	Vertical heterophoria (in prism diopters)
Ophthalmoscope (large)	-4.89	-0.03
Flashlight (small)	-4.87	+0.03
Difference	0.02	0.06
Standard error of difference	±0.39	±0.12
Coefficient of correlation	±0.90	±0.85

Note: - = exophoria; + = esophoria

- = left hyperphoria; + = right hyperphoria.

-oOo-

PROJECT SG-106

This is a preliminary (progress report) study of the relationship between (1) age, (2) sex, (3) heterophoria at 20 feet and at 13 inches, (4) prism convergence and prism divergence at 20 feet and at 13 inches, (5) the near point of convergence, and (6) the refractive error of each eye separately.

In so far as we are able to determine, this is the first such study made to determine the relationships, if any, between heterophoria and the other points just enumerated. The only partially similar study was made by Haessler (Am. J. Ophth. 21:272, 1938) in which he considered the realtionship of heterophoria at 20 feet (measured with a Maddox rod) to prism divergence at 20 feet and the convergence angle. His sample consisted of 1,000 cases and was pre-

selected to the extent that the following subjects were eliminated:

(a) those with more than 0.5 prism diopter of hyperphoria
(b) those with more than 4 diopters of ametropia
(c) those who had not worn correcting lenses for their ametropia for at least several months.

Haessler justified his use of the Maddox rod test for heterophoria on the basis of a study by Weymouth (Ophth. Record, 25:271, 1916), who used 12 subjects and concluded that the screen and parallax test, von Graefe's prism diplopia test, and the Maddox rod test were equally reliable at a testing distance of 20 feet. Weymouth's work has since been confirmed (Scobee and Green, Am. J. Ophth., 30:436, 1947).

As has been pointed out, Haessler measured prism divergence at 20 feet, but he calculated convergence as the convergence angle using the PcB (the near point of convergence). He then studied the distribution of heterophoria for each category of prism divergence, i.e. , 1, 2, 3, 4, 5, etc., prism diopters, as well as for each category of the convergence angle. He concluded that there was a complete lack of correlation between heterophoria and vergence as he studied it, and wrote "....in 1,000 patients who came for a refraction, it was shown that the degree of exophoria or esophoria was not determined by a balance between divergence and convergence as experssed in the usual clinical measurements."

One other study might be mentioned. It was made by Abraham (Am. J. Ophth., 26:271, 1943), who studied 4,000 patients with respect to their heterophoria and ductions (vergences) both at 20 feet and at 13 inches. He was primarily interested in the possibility of predicting the symptoms of a patient from the findings in the measurements either of heterophoria or vergences. Although he made no formal statistical analysis, his conclusion was that the only finding of significance, i.e., which would allow the prediction of symptoms, was the prism divergence at 13 inches. His work has been confirmed (Scobee, 1944) and has been recently restudied (Scobee and Green, 1947).

In our preliminary report, 214 subjects have been studied. Data have been collected on a total of 400 subjects. It appears that the final results as determined by the larger sample will not be appreciably different from those on the 214 subjects in this preliminary report.

A summary of the results may be made in two parts. First, we want to see if variations in age or variations in visual acuity are associated with variations in the amount of lateral heterophoria or of vergence. Our sample of 214 subjects furnishes no evidence for such associations, as we shall see later. Second, we want to see if the amount of lateral heterophoria is associated with the amount of convergence or divergence at both testing distances, 20 feet and 13 inches. At a distance of 20 feet, we found a relationship between heterophoria and convergence, and between heterophoria and divergence, but neither relationship was intense enough to indicate that one measurement could be subsitituted for another in routine testing. At a distance of 13 inches, we found a relationship between heterophoria and divergence, but we can neither claim nor deny that there is a relationship between heterophoria and convergence. The results, therefore, are substantially in agreement with the conclusions both of Haessler and of Abraham, although approaching the subject from an aspect different from that used by either of them.

<u>Age vs. Heterophoria and Vergences</u>. In the sample of 214 patients, there

was no evidence that age is functionally related to the amount of heterophoria, or to prism convergence or prism divergence when all are tested both at 20 feet and at 13 inches. Because of this result, it was not necessary to adjust the heterophoria and vergence readings for varying ages of the patients. The observed coefficients of correlation between age and the other variables along with the tests of significance are given in Table II.

<u>Refractive error vs. Heterophoria and Vergences</u>. The refractive error of these 214 patients appeared not to be related to the amount of heterophoria or to the amount of either prism convergence or prism divergence at either 20 feet or 13 inches. This assertion is based upon the coefficients of correlation relating the refractive error to the other variables. In every case the coefficients were not significant as may be seen in Table II. An adjustment for refractive error was, therefore, not regarded as necessary.

<u>Heterophoria vs. Vergences</u>. At a testing distance of 13 inches, a correlation between prism divergence and heterophoria was found. The correlation coefficient, -0.30, implies that lower amounts of divergence accompany greater amounts of esophoria and that larger amounts of divergence accompany greater amounts of exophoria. To be judged significant with a 1% chance of being in error, the coefficient of correlation should exceed $\pm$0.17. A correlation between prism covergence and heterophoria at 13 inches was not estimated, owing to the nature of the distribution of covergence. The maximum convergence recorded was 30 prism diopters and 149 of the 214 patients were recorded as having this amount. Actually many of these 149 patients may have had more than 30 diopters of convergence, but the Risley rotary prism is not scaled to measure larger amounts. The result is a truncation of the distribution at 30 prism diopters.

At a testing distance of 20 feet, there was no significant association between the amount of heterophoria and the amount of prism convergence or divergence. The coefficients of correlation, +0.14 for heterophoria and convergence and +0.12 for heterophoria and divergence, are just large enough to suggest that there may be a tendency for larger amounts of convergence to be accompanied by larger amounts of esophoria.

A comparison of prism divergence at 13 inches with heterophoria at 20 feet shows that these two functions are related. The coefficient of correlation was +0.30 which implies that larger amounts of divergence at 13 inches are associated with greater exophoria at 20 feet and that smaller amounts of divergence are associated with greater esophoria.

The practical application of the results of these studies to the armed forces can be summarized easily. Tentative suggestions for a revised visual examination for flying personnel have been submitted to the Surgeons General of both Army and Navy. Suggested changes were as follows:

(1) Heterophoria to be tested at 20 feet but prism divergence at 20 feet to be omitted. The results of this study, at least, imply that such an omission is entirely justified in as much as there is no demonstrable relationship between these two measurements.

(2) Prism divergence to be tested at 13 inches, with a pass-fail minimum score of 12 prism diopters required. This is not required in the present examination. The demonstrated relationship between prism divergence at 13 inches and heterophoria both at 20 feet and 13 inches is ample reason for including such a measure in the examination.

(3) It was the expressed belief of representatives of both Army and Navy that pilots for regular commission in either service might pass the new heterophoria limits as suggested, but as they advanced in age they might fail to pass the same limits. The justification for keeping the same limits, irrespective of age, is apparent since there is no demonstrable correlation between age and either heterophoria at 20 feet or prism divergence at 13 inches.

References

Abraham (1943) Am. J. Ophth. 26:271

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TABLE II.

The relationships between age, refractive error, heterophoria, convergence and divergence in a sample of 214 patients.

	AGE	REFRACTION		20 FEET			13 INCHES		
		OD	OS	HETERO-PHORIA	CONV.	DIV.	HETERO-PHORIA	CONV.	DIV.
MEAN	34.1	+0.13	+0.05	+.98	17.87	-6.73	-3.36	28.04	-20.60
STANDARD DEVIATION	13.1	1.59	1.63	2.91	6.21	2.83	4.47	4.28	4.80
COEFFICIENTS OF CORRELATION									
AGE				-0.07	-0.06	-0.03	-0.08	X	+0.11
HETEROPHORIA					+0.14	+0.12		X	-0.30
REFRACTION									
OD				+0.03			+0.11		
OS				0.03			0.00		

NOTES: To be judged significant with a 5% chance of being in error, the coefficient of correlation should exceed ± 0.13; with a 1% chance, it should exceed ± 0.17.

Lateral heterophoria: + = esophoria - = exophoria
Vergences: + = convergence - = divergence

Discussion:

Dr. Ogle asked whether Dr. Scobee meant to imply that individuals did not undergo changes in heterophoria with changes in age.

Dr. Scobee reported that his data were not longitudinal studies on the same subjects but rather random samples from various age groups. His data indicated no change in the group mean of heterophoria with age.

Dr. Grether raised the question whether there could be selective factors involved in the groups Dr. Scobee used which would explain the equivalence of the means of heterophoria for different age groups.

Dr. Scobee replied that the population used was as nearly random as possible, consisting of hospital employees, general patients, and patients with refractive complaints.

Dr. Imus reported in his paper that he had omitted to report that within an age range from 20 to 30 years, there was no relationship between age and near point of convergence or between age and acuity.

Dr. Berens asked for a clarification of why Dr. Scobee planned to rule out near point of convergence as a test measure. Dr. Berens menti oned that he had found this measure to be a good indicator of low nervous tone.

Dr. Scobee replied that he felt there were other measures of more value in predicting what an individual will do over long periods of time than the near point of convergence.

Lt. Commander Webster raised the question that although correlations found by Dr. Scobee were statistically significant, they might be so small that their predictive value was negligible.

Dr. Scobee replied that his statistically significant correlations were of the order of 0.3 to 0.4.

Lt. Comdr. Webster then made the point that with such relatively low correlations, there was a large amount of variance unaccounted for.

ABSTRACT OF COLONEL WILLIAM S. STONE'S REPORT ON NEEDS FOR VISUAL TESTING IN THE ARMY

Colonel Stone, discussing general problems of vision testing in the Army, made the point that in the past medical selection had been based on a "philosophy of plenty". He reminded the group that during the closing phases of the war the supply of personnel had become nearly exhausted, and that accordingly a more critical philosophy needed to be adopted with respect to the rejection of potential military personnel.

Colonel Stone made the general point that men who are medically imperfect are often able to compensate and become effective military personnel. He emphasized the need for more psychological research in medical problems so that the ability of men to compensate for defects would be more adequately evaluated in rejection of personnel.'

Colonel Stone mentioned that on many occasions the Army has waived visual defects in the commissioning of officers, but that unfortunately data are not abailable indicating whether visual defects had a significant influence on their Army careers. He also emphasized the need for adequate job analyses of military occupations so that there would be optimum use of available personnel.

Discussion:

Dr. Dimmick asked whether Dr. Geldard's job analyses of Army occupations had been found generally useful. It was reported by Dr. Grether that these job analyses were more for general psychological traits than for vision.

FLUORESCENT SIGNALING DEVICES EMPLOYED IN NIGHT CARRIER LANDING OPERATIONS

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I. Introduction

The procedure of launching and landing aircraft aboard carriers since its inception, has always been considered relatively hazardous, especially so at night. Although the impetus of the war years brought many refinements to carrier operations, both in material and technique, carrier procedure still remains hazardous when compared with land based aircraft procedure. Expecially is this true for night carrier operations, as borne out by the fact that the Navy has abandoned training its specialized night carrier squadrons. I am not cognizant of the official reasons for this decision but one can conjecture that night carrier squadrons would continue training if the hazard was not out of proportion to the peacetime concept of what constitutes safety in training.

However, consideration of the uncontestable importance of night carrier operations as a military weapon demands that it be continued and developed at least to the point where it is on a par with daytime carrier procedure with respect to safety. The present study was opened with this objective in mind.

Since the most apparent difference between day vs. night carrier procedure is the amount of light available and permissible, it is not surprising that the visual aspects of the problem have been selected and emphasized for first consideration.

Grossly, the procedure suggests two distinct visual problems. One for the LSO, in seeing the approaching aircraft, and the second for the pilot, in seeing the LSO and discriminating his signals.

It was felt that the pilot's visual problem was more amenable to correction and consequently this factor was attended to first.

A simple empirical experiment was outlined utilizing a number of small LSO models scaled to represent a six-foot LSO as seen from distances of 200, 400 and 800 feet astern the carrier. The models were dressed or painted into a variety of costumes, utilizing every color available and every geometric design which suggested itself. They were observed from a distance of 20 feet in a blacked out room by two judges. The basis for judgment was a suit and paddle design which had been popular aboard a carrier. This was our standard. Those designs which seemed to offer better visibility and discrimination of detail than the standard, were given an arbitrary rating, and the designs which seemed poorer than the standard were discarded. Thus, by the method of elimination, trial and error, a basic type of design emerged and the best of the several colors was noted.

However, we soon realized that we were unable to choose the best single design or the best single color by this method of evaluation. That is, the differences among the better designs was not great enough to permit the sensory-

perceptive mechanism to make selective distinctions under the conditions of the experiment. Upon re-evaluating the experiment, it was felt that failure to achieve our objective resulted from: (1) working with an arbitrary standard, rather than a standard based upon sound visual principles, and (2) the error of trying to evaluate subtle visual differences under non-threshold conditions.

However, this initial experiment, subjective and empirical as it was, did provide us with a few generalities which were accepted as working hypothesis - namely that (1) simplicity of geometric pattern, (2) employment of fewer colors simultaneously, and (3) small total areas of fluorescent fabric were the outstanding characteristics of the LSO suits with the highest ratings. Shortly after these laboratory tests were completed, we learned that a group of N A S, Barber's Point, Honolulu, had also done some field testing along lines similar to our own. It is of interest that the suit which they considered superior was very similar to one of our top rated suits in color and design, differing only in minor respects.

In the course of the above experiments, a number of other variables were superficially investigated, such as silhouetting the LSO against a fluorescent background, dialing of the background with fluorescent material, using an animated LSO model, etc. However, evaluation of any of these factors met with the same objections mentioned earlier in regard to the evaluation of the suits.

It was felt that real progress would have to await an objective method of accurately measuring the luminosity of the fluorescent colored fabrics, and a plan for a visual experiment in which the variables could be controlled to attain threshold conditions.

Optical instruments for measuring the luminous emission of fluorescent solutions are standard laboratory equipment. Adaptation of the Beckman spectrophotometer for solid fluorescent materials suggested itself and was attempted. In the initial trials the filtered U V radiation was passed through the porous fabrics and the intensity of the resulting emitted visible radiation was measured as a function of wave length. It was anticipated that opaque fluorescent materials might be encountered and the final adaptation (Fig. 1) was designed. The specimen is activated by the U V band at a 45° angle on its emitting surface. The emitted fluorescence is concentrated into the entrance aperture of the spectrophotometer by a glass lens.

The photocell in the Beckman instrument was calibrated against incandescent tungsten radiation. The relative energy of the fluorescent radiation was calculated from the relative energy of a black body radiator at the same Kelvin temperature as the tungsten source and multiplied by the luminosity factor of the eye. Most of the studies employing fluorescent fabrics have been made with slit widths between 0.1-0.3 mm.

This adaption gives the relative luminosities of the several fluorescent fabrics. The character and degree of deterioriation of fluorescence with weathering and exposure can be determined and newly developed materials submitted by manufacturers can be compared with known samples.

Since the Beckman spectrophotometer is expensive and requires some degree of technical ability for operation, a simpler device was constructed. This device utilizes a small filtered UV source to activate the fluorescent sample at a 45° angle. The emitted visible fluorescent radiation is received

at a 90° angle by a Weston photronic cell which is equipped with a Viscor filter. The photo current is read from a sensitive Rubicon microameter. The Viscor filter and photronic cell combination has a spectral sensitivity comparable to that of the eye and therefor does not require calibration.(Fig. 2)

The simplicity of construction and operation of the device makes it suitable for the use of inexperienced personnel in the localities where fluorescent materials are being used. Although the spectral distribution of the fluorescent fabrics cannot be determined with such a device, the relative luminosities can be determined with it in less than 1 minute per sample. It also serves as a check for the relative luminosity data obtained via the spectrophotometer.

It is of interest to note that orange has the highest luminosity value among the fluorescent colors tested. Observers frequently selected green and red to have the highest luminosities. This response is probably conditioned by its identity with traffic signal colors and color contrast rather than the property of brightness. Therefore, since color contrast is not too important in night LSO communication, orange colored fabrics should on the most significant portions of the signaling devices.

Since the spectral composition of the fluorescent radiation is somewhat more monochromatic than that usually obtained with filters, an apparatus was designed and constructed to permit visual acuity determinations under simulated night conditions, employing the fluorescent colors as the light source. The apparatus permits the control of such variables as light intensity, color, contrast, time, and area, size and complexity of target.

Since each parameter of vision can be tested singly or in combination with others, it is hoped that a tentative solution will be forthcoming for the problem of LSO visual communication devices, particularly the amount of fluorescent material and the geometric pattern that will provide the most discernable signals.

The color analyzing apparatus and the night visual acuity device described above is not of course limited to LSO investigation. The problems of visibility and recognition of air search and rescue equipment are constantly receiving attention. Empirical field tests have demonstrated that the fluorescent orange is the most frequently selected as the most discriminable color at sea under daytime conditions. However, the methods employed to determine the shape, size and proper color contrast of field equipment are largely on an empirical basis, reminiscent of the kind of tests mentioned earlier in connection with our evaluation of LSO suits on models. The implication of this analogy is that the results have been and will continue to be controversial to some extent, principally because the handicaps of uncontrollable conditions and human variability have not been eliminated or at least minimized.

Summary and Conclusions

In summary:

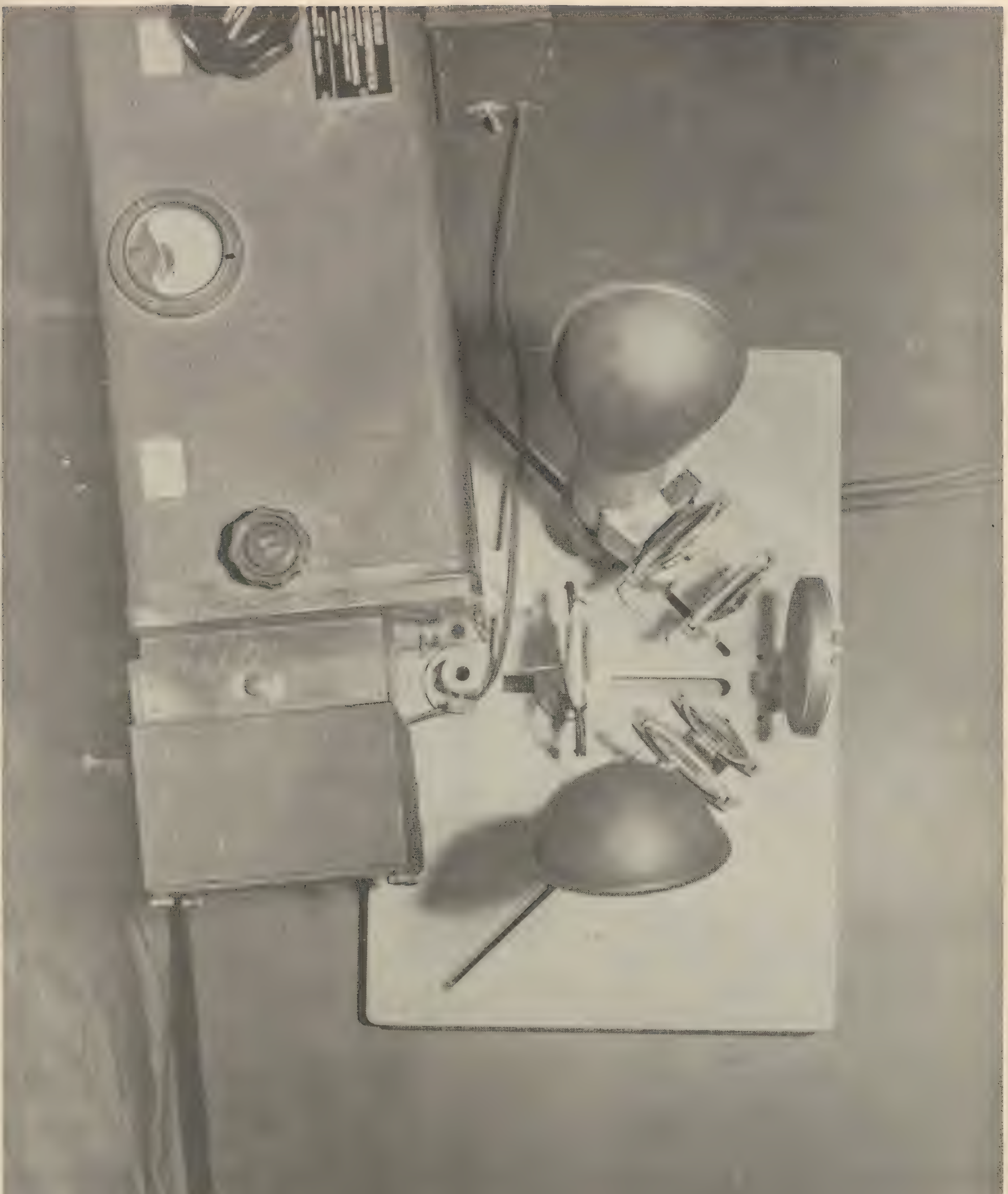
1. The hazard of night carrier operations and the need for improvement in technique was emphasized.
2. The initial empirical work was described, with reasons why its limitations were cause for rejection of the method.
3. Two pieces of apparatus were described which can provide the color and luminosity information about fluorescent fabrics.

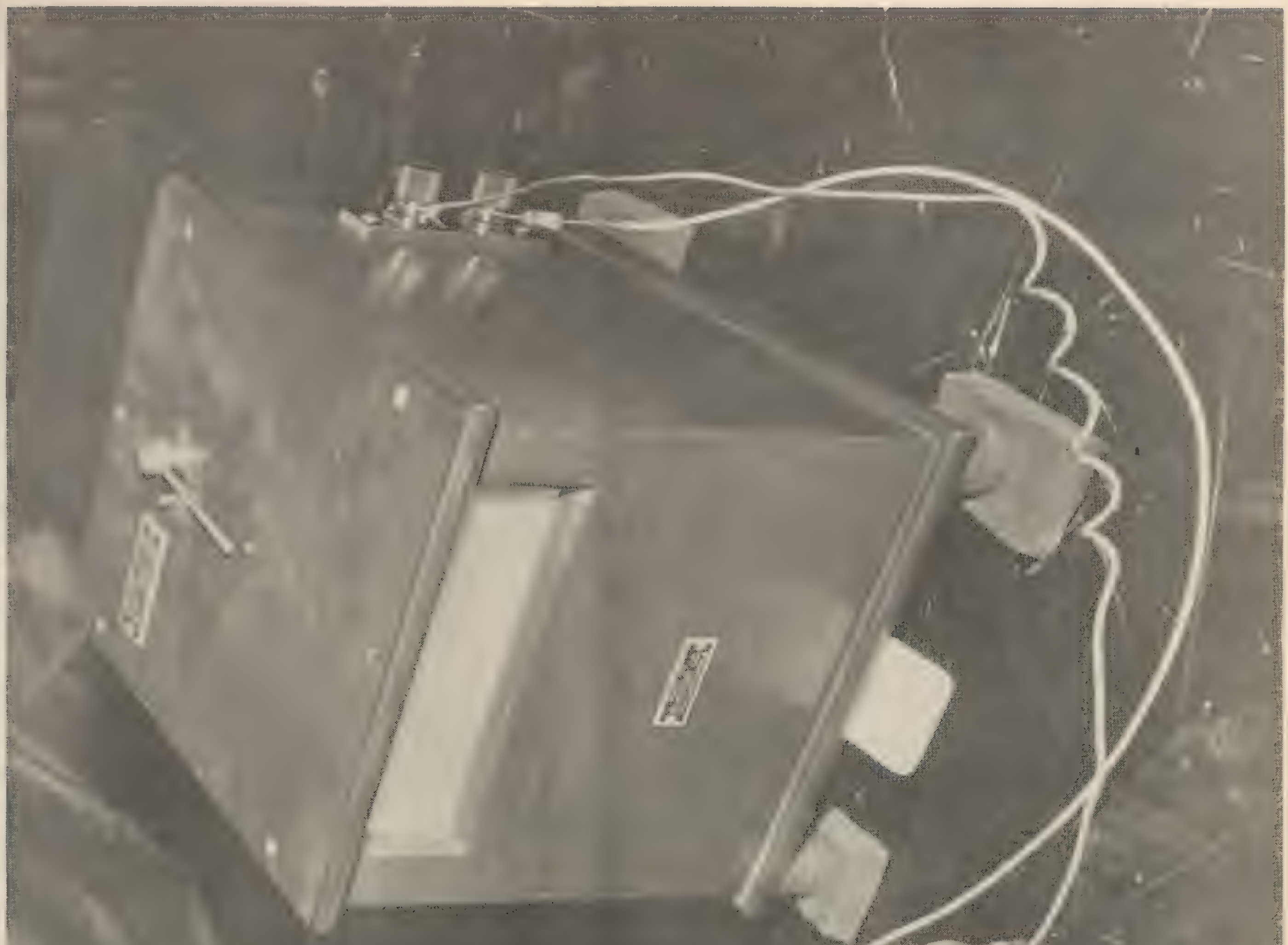
4. A visual discrimination device using fluorescent colors for target illumination is mentioned. However, no data has yet been collected with it, so that its value is still undetermined.

Discussion:

Mr. Breckenridge asked Lt. Schiller about the fluorescent standard that he used.

Lt. Schiller explained that the standard was a piece of metal with imbedded fluorescent glasses backed by magnesium carbonate.





A PROPOSED HANDBOOK OF VISIBILITY

S. Q. Duntley

More than five years ago the Navy requested the NDRC to undertake research intended to result in a handbook of visibility. Although circumstances during the war did not permit such a handbook to be written, the eventual preparation of such a volume was always in the minds of those responsible for planning and directing the vision research program of NDRC Section 16.3. The desire for such a handbook has subsequently been voiced on numerous occasions by personnel of the Vision Committee, and at the time of the meeting of the Sub-committee on Atmospheric Optics last March I suggested that the nucleus of a handbook could be brought into being simply by assembling selected paragraphs from Volume 2 of the Summary Technical Report of NDRC Division 16. I volunteered to illustrate my suggestion by pasting together a series of clippings from the STR, and to this end a set of page proofs was requested of OSRD by the Vision Committee. However, the speed of official channels proved to be too slow to obtain the proof in time for this meeting, and therefore the presentation of this embryo handbook of visibility must be postponed.

Discussion:

Dr. Ballard reviewed the history of the proposals for a handbook on visibility, indicating the long-standing need. He emphasized the necessity for utilizing the "memories" of various persons who were concerned with visibility problems during the war in the preparation of such a handbook so that indoctrination of a completely new group would not be necessary.

Dr. Blackwell explained the most recent conditions from which the demand for a handbook had arisen. He explained that the Naval Sciences Division of the Office of Naval Research had indicated in informal discussion that a handbook was desirable so that visibility information could be made maximally useful to the operational groups in the Navy.

Dr. Blackwell suggested that the preparing of manuals should be accomplished by the Naval Science Division of ONR, but that such a manual should be prepared under advisement of a Subcommittee on Visibility of the Vision Committee. Such a Subcommittee would include the "memories" of Dr. Ballard and others who had been intimately concerned with these problems during the war.

Dr. Imus concurred in the suggestion that a Subcommittee be set up to work with the Applied Sciences Division of ONR.

Dr. Marquis summarized the discussion by suggesting that the Vision Committee be alerted with respect to the problem of the handbook and that when the need was apparent, a subcommittee be established.

EXPERIMENTAL PROGRAM OF THE VISION LABORATORY, UNIVERSITY OF MICHIGAN

H. Richard Blackwell

I. Background

In 1942, the prevalence of military operations involving visual detection and recognition of targets created an urgent need for a large body of experimental data. Although a great store of information concerning visual phenomena was available, the existing data were not considered adequate to place the solution of visibility problems on an engineering basis. The chief reason for this inadequacy was that experimentation in vision had simply not been directed toward "visibility engineering".

Several experimental programs were undertaken during the war years to provide the indicated threshold data, both for the unaided eye and for the eye aided by telescopic systems. The studies were made by N.R.L., Dartmouth, Brown, the University of Rochester, and the Tiffany Foundation. A paper I presented previously before the Vision Committee indicated the general agreement of all the experimental data obtained during the war years, provided allowances were made for the differences in experimental procedure.

In spite of the rather staggering amount of experimental data collected by the various programs, any attempt to apply existing data to the solution of visibility problems reveals that only a small fraction of the necessary data are available.

Data are available expressing the contrast thresholds for detection of uniformly bright stimuli seen against uniform surrounds. The data were obtained either with a fairly arbitrary search time, or with an unlimited search time. Only a restricted area of the retina was explored: the fovea at high brightness, and one portion of the parafovea at low brightness.

For evaluating the probability of detection of a rapidly moving target, such as an aircraft, unless we are to investigate every conceivable target path, combined with every conceivable search procedure, we need to determine elemental data--data predicting the probability of detecting the target during each small interval of time, at each retinal position. Contrast thresholds need to be determined as a function of duration of the stimulus for each of many points on the retina, at each of a range of adaptation brightnesses. These functional relations must be understood for targets of various sizes, shapes, and patterns of non-uniformity. In addition, methods of predicting the total probability of detection from the elemental data must be developed.

A similar program is required for recognition thresholds. In order to chip away at the backlog of requisite data, a vision laboratory was established at the University of Michigan. Work was begun in July 1946, under contract with the Medical Sciences Branch, Office of Naval Research.

The number of experimental conditions to be investigated is seen to be enormous. In view of the magnitude of the task, it was decided that experiments should first be conducted to determine the most efficient procedures for use in the main body of experiments. Two main points of procedure need-

ed to be clarified: first, the range of viewing distances equivalent to the long viewing distances encountered in military problems, and second, the most efficient and valid psychophysical procedures. The work of the vision laboratory to date has been concerned with these two preliminary investigations.

II. Distance and Visual Function

Since Aubert and Forster, some eighty years ago, the literature has been replete with experiments concerning the influence of distance upon visual function. Careful perusal of these experiments leads to only one conclusion: that there is no convincing evidence that visual functions of the emmetropic eye are dependent upon visual distance, provided other usually concommitant variables are removed from the experiment. In every experiment reported in the literature, either a psychophysical procedure was used which could have reflected the observers' attitude or else apparatus was used which did not yield comparable stimuli at the various distances tested.

We might ask what mechanism could exist for the emmetropic eye which would result in visual function being dependent upon distance, provided adequate psychophysics were used. Let us consider the rapid, minute fluctuations of fixation which Adler and Fleigelmann have shown to exist. It seems consistent with the findings of muscle physiology that the fluctuations should increase in magnitude with increased convergence tension of the extrinsic muscles, although there is apparently no experimental evidence as yet on this point. When this suggestion was made to Dr. Conrad Berens, however, he stated that he had observed such a phenomenon in clinical practice.

Since the amplitude of the fluctuations of fixation could influence visual thresholds, we have postulated a mechanism whereby visual thresholds could increase with decrease in viewing distance. We would expect the influence of the fluctuations to vary with different stimulus objects. If the stimulus were large and the criterion were detection, we might expect to find no effect. But for small stimuli, expecially if resolution were the visual task, we might expect to find a significant increase in threshold with decrease in distance.

An experiment has been conducted in which the detection threshold for a 1 degree circular stimulus was determined for five viewing distances varying from 1.9 to 30 feet. Care was taken to insure that the stimuli were equivalent at the various distances. Data are available for five observers, none of whom had a refractive error greater than 0.5 diopter: three being slightly myopic, two slightly hyperopic. The data indicated clearly that there was no difference in threshold for the range of distances investigated for any of the observers.

Apparatus has been completed, and experiments just begun on the resolution experiment. To obtain resolution objects for the experiment, a clever technique reported by Hulburt and his associates was used. A plano-convex lens is adhered to a transilluminated opal glass screen. The stimuli are produced by illuminating the assembly from two point sources, separated by the desired amount. A virtual image of the point sources is formed by reflection off the convex surface of the lens very near the plane of the opal glass screen, greatly de-magnified.

III. Psychophysics in Vision Experimentation

Experiments have been conducted to determine the equivalence of various

psychophysical procedures used in obtaining visual thresholds. The two basic methods compared were: (1) forced guess; and (2) "Yes-No". In the first method, the observer is forced to respond concerning some attribute of the stimulus, and it is always possible, accordingly, to obtain an objective evaluation of the responses made. Two kinds of "forced guess" have been used: spatial discrimination, and temporal discrimination. In the first type, the stimulus can appear in one of several locations. The observer is required to discriminate the position occupied by the stimulus on each trial. In the second type, the stimulus occupies only one spatial location, but there are a number of possible moments in time when the stimulus can be in the specified position.

In either temporal or spatial "forced guess", there are a specified number of correct responses which result from chance. If there are four temporal intervals from which to choose, for example there is a 25% chance of guessing the correct interval in the absence of visual discrimination. The psychometric data must be converted to remove the chance successes. The conversion is standard: for each three incorrect responses at a given stimulus value, there is a fourth response which should have been incorrect but which was correct by chance. Conversion involves removing this spuriously correct response from the experimental scores.

In the "Yes-No" procedure, the observer sets his own criterion of confidence as to the presence of the stimulus. The experiment consists of a number of trials in which the stimulus appears at various contrasts, interspersed with a number of trials in which the stimulus is not allowed to appear. The frequency of "Yes" responses to the blank trials is taken as a measure of the attitude of the observer, and is used in the same way as a chance score correction in reducing the number of correct percentages. After practise, all observers with whom we have worked develop a response pattern in which there is practically never a "Yes" response to the blank trials.

In using the spatial type "forced guess" method of Tiffany, it was found from interrogation of the observers that they were not confident of having discriminated a stimulus unless the percentage of correct responses, converted for chance, exceeded approximately 80%. This should mean that if the observers had been asked to respond "Yes" or "No" concerning the presence of this stimulus, they would have said "No" for stimulus values at which they were able to obtain 80% correct responses with a forced guess technique. We should therefore expect that the threshold contrast obtained with a "Yes-No" method would be significantly higher than the corresponding value obtained with a forced guess method.

An experiment conducted on four observers indicated that the threshold contrast obtained with the "Yes-No" method was indeed higher than the value obtained with the forced guess method. In addition, the slope of the psychometric function was flatter with the forced guess method, indicating that the top of the two functions were identical but that the forced guess method brought out additional correct responses obscured by the arbitrary "Yes" criterion adopted by the observer.

A subsequent experiment was conducted, designed to determine whether the observers could be induced to respond "Yes" to the stimuli which could be discriminated, indicated by correct responses on the forced guess method, but which normally were given a "No" response. Attempts to persuade the observers to reduce their criterion for "Yes" were not successful, probably because the observers had had considerable experience in the "Yes-No" response. An experiment was then conducted in which the difficulty of the stimuli was markedly in-

creased. In this experimental situation, the observers would have been expected to make a small proportion of "Yes" responses. Actually, they made considerably more "Yes" responses than would have been expected, without increasing the number of "Yes" responses on the blank trials. It appeared that the observers were attempting to reach the usual proportion of "Yes" and "No" responses, even though the actual values of stimuli presented called for far fewer "Yes" responses than usual. The threshold obtained with the more difficult experimental situation was therefore found to be significantly lower than the threshold obtained with the normal difficulty experimental situation. However, even with the more difficult situation, threshold contrast was significantly higher than with any forced guess procedure. Comparable experiments with forced guess psychophysics indicated no change in threshold for the same change in the difficulty of the experiment.

The experiment reported above indicated that the "Yes-No" psychophysical method is invalid, its threshold depending upon the attitude of the observer in an easily demonstrable manner. The method of adjustment and the method of limits, both frequently used in determining visual thresholds, call for fundamentally "Yes-No" responses, and probably exhibit the same invalidity, although it is somewhat more difficult to demonstrate this fact experimentally.

A number of variations on the two types of forced guess psychophysics were investigated to ascertain whether equivalent thresholds were obtained. Temporal and spatial discrimination in which there were two and then four possibilities were compared and all found to yield the same threshold, after the appropriate conversions were made. The various stimuli were presented randomly in the sequence, and they were grouped into groups containing 5, 10, 20, 30, and 40 stimuli of the same magnitude in succession and the thresholds obtained under all the conditions investigated were shown to be equivalent.

Another variation was investigated in which the fourteen stimuli used for the experiment were presented in a graduated sequence, beginning first with the greatest stimulus, and descending to the smallest, and then ascending from the smallest to the greatest. The threshold obtained in this way was equivalent to those obtained with all the other forms of the forced guess method. It was found that the threshold obtained with ascending order was equivalent to that obtained with descending order, a novelty for psychophysical data.

These experiments indicate the desirability of utilizing a forced guess psychophysical method in vision research, since it alone possesses validity. Work in the vision laboratory is progressing to enable us to specify the most efficient variation of the forced guess procedure. Preliminary results indicate that grouping the stimuli of the same magnitude together permits greater stability of response than if the stimuli are randomly distributed throughout the experimental session.

Additional work is being conducted to determine the shape of the psychometric function with a valid psychophysical procedure. Preliminary evidence indicates that when the stimuli are grouped, the psychometric function is an acceptable fit to a normal integral. When the stimuli are randomly presented, the function is skewed and resembles more closely a cumulative Poisson distribution or the integral of a log normal distribution.

An attempt has been made to isolate the nature of the variability which is responsible for the psychometric function. The possibility was investigated that the psychophysical variation is cyclical in nature, as Lee and his

colleagues have reported. Data on several observers in which the method of adjustment was used failed to reveal any cyclical variation. In a second experiment, utilizing the temporal forced guess procedure, the same stimulus was presented repeatedly for a two hour period. An analysis of the data was made which also indicated the absence of cyclical variations.

Analysis of our data indicates that there is very little long-duration variability, that is, variations in sensitivity which would appear if the data were averaged for periods of several minutes each. Such long-duration variability would be expected to occur if the observers showed fatigue or practice effects.

It can be shown that during a two hour session, the threshold remains relatively constant, but the slope of the psychometric function shows considerable, independent variability.

IV. Proposed Field Study of Visual Detection

When we attempt to apply laboratory vision data to the prediction of the range of visual detection in the field, we are always aware of the many differences between the two situations. Laboratory observers are comfortable and rather uniformly motivated whereas in the field neither of these conditions can be said to exist. Because of the large number of observations made in the laboratory, chance factors are minimized compared with conditions in the field. These differences in conditions result in random differences in results between the laboratory and the field. Perhaps the only means of evaluating the magnitude of random differences is to conduct a full-scale field study in which conversion factors and engineering tolerances can be determined for various field conditions.

Because of the tremendous difficulties encountered in a full-scale field study, it is desirable to make the conversion from laboratory to field in several steps. The field study of visual detection to be described here is intended to be the first step in the process.

The basic plan is to duplicate the psychophysical conditions of the laboratory but to utilize typical field conditions in all other particulars.

Detection thresholds in the field will be determined with controlled psychophysics under a wide variety of natural conditions. Measurements are to be made with the unaided eye and with various telescopic systems. The program will be conducted with the close cooperation of the Optical Inspection Laboratory, Pennsylvania State College.

The primary facilities consist of seven fire-lookout towers, located in a relatively uniformly forested area in Northern Michigan. The towers have been made available through the cooperation of the Michigan Department of Conservation and the United States Forest Service. Viewed from the central tower, the six target towers are visible against the sky at distances of 6, 10, 14, 15, 21, and 30 miles. The cabs of the towers, where the targets will be located, are 70 to 100 feet above the ground. Nearly the entire structure of each of the target towers is visible against a sky background.

Two kinds of targets will be used: billboards and signal lights. The bill board targets will measure 6 by 12 feet. In addition to those mounted on the tower cabs, several will be mounted on the ground at distances of 1 and 2 miles. Provision will be made for the integrated reflectance of the bill-

board targets to be varied continuously from approximately 4 to 85%, thus varying the contrast of the targets against the sky from nearly -1. to +5. These targets will be observed with the unaided eye and with telescopic systems against the daylight and twilight skies. For night work, one of the targets on the ground will be independently illuminated. The signaling light used as a target will be a standard Navy 12-inch signaling searchlight, rated at approximately 200,000 candles. It will be mounted on the roof of the tower cabs, and will thus be viewed against the sky for restricted conditions in the daytime, for twilight, and for night conditions, being viewed both with the unaided eye and with telescopes.

It will be necessary to mask the structure of the target towers so that the entire tower is invisible except for the target. This objective will be accomplished by mounting reflector-lamps at a number of points on the structure of the tower, adjusted in intensity so that they add just sufficient luminous flux to compensate for the low reflectance of the tower structure.

An observation post will be constructed in the central tower, at a position approximately 50 feet above the ground. This post will consist of a platform approximately 15 feet square, on which are mounted the observer and the recording instruments. Care has been taken to insure that the contrast of the target at the eye is adequately evaluated. Three basic photometers will be used: one photographic, one photoelectric, and one visual. The basic photographic equipment will be a 16 mm. movie camera, used in conjunction with a high-power telescope. A special telephoto objective with a focal length of 40 inches, operating at f/5., has been generously loaned to the project by the Optical Research Laboratories, Boston University.

The photographic record will be used in two ways. In the first place, it will be used to determine the magnitude of atmospheric boil during the experimental sessions. A reticle will be mounted in the telescope as a reference point, from which deviations of the target due to boil can be determined. When it is desirable, the photographic record can be used for photometry of the contrast of the target by sensitometry.

The photoelectric photometer has been developed for the project by Professor Nottingham of the Massachusetts Institute of Technology. There are two photometers, each developed around a 931 photo-multiplier tube. One photometer is arranged to record the flux reaching the phototube through a telescopic system from an area of sky adjacent to the target. The other photometer responds to the flux coming from the target and area of sky around it large enough so that no portion of the target is ever deviated out of the field by action of atmospheric boil. The voltages from the two photometers are bucked against each other and a special recorder is calibrated to record the equivalent contrast of the target as a function of time.

Finally, a visual photometer will be used, constructed on the principle known as the Maxwellian view. This instrucment will measure a quantity proportional to the total luminous flux coming from the target and an area of sky large enough so that no portion of the target is ever deviated out of the field by atmospheric boil. It will then be used to measure the flux from an area of sky adjacent to the target.

For the targets subtending the smallest visual angle at the eye of the observer, the most pertinent quantity to measure is undoubtedly the flux difference of the target, which is measured by both the photoelectric photo-

meter and the visual photometer. For these targets, the photographic record will be used principally to describe the amount of atmospheric boil present during the experiment. For targets of angular subtense above the resolving limit of the eye. unaided or with binoculars, the distribution of brightness of the target image is of great interest. For these targets, sensitometry will be performed on successive frames of the motion picture record.

A meteorological observer will record all pertinent data to provide a complete meteorological description of the weather conditions at the time of the experiment.

A sample experiment might profitably be described: Consider the unaided eye threshold for a reflecting-type target by day. The observer will take up his station at the observation post. The target visible at the greatest possible distance for the obtained weather conditions will be selected. A towerman will first adjust the masking lights. At the observation post, an assistant will observe the tower masking lights through a visual telescope and will direct the towerman by walkie talkie. When a satisfactory match is obtained in this way, a check will be made on the adequacy of the masking with the photoelectric photometer. The visual photometer will be used only occasionally as a rather clumsy check on the validity of the photoelectric instrument.

The observer will then take up his post and advise the towerman by walkie talkie with regard to the adjustment of the target reflectance. The target will first be adjusted to a reflectance. which can not be detected with the existing illumination conditions. The towerman will either increase or decrease the reflectance, depending on which threshold is desired, adjusting continuously until the target is just visible. The observer will operate the motion picture camera to obtain a record of the condition of the target at the moment of threshold. The assistant operating the photoelectric photometer will mark the continuous record of contrast at the moment of threshold. The whole procedure will then be repeated until sufficient psychophysical data are available to yield reliable results.

At the moment of threshold, the towerman will photometer the inherent contrast of the target. This measurement, together with the measurements and computation of contrast at the observer's eye will permit a calculation of the contrast reduction of the atmosphere. This datum will be used merely to describe the condition of experimentation.

The same experiment will be conducted on various days,and the threshold contrasts obtained will be examined with respect to all the recorded variables to see whether there are functional relationships. It is anticipated that for the targets subtending the smallest angles at the eye, none of the recorded variables will show a functional relationship to threshold contrast. When the angular subtense exceeds the limit of resolution of the eye, it is anticipated that the threshold contrast will be a function of atmospheric boil. There may be other unexpected functional relations. The purpose of the research is to discover variables other that those normally considered in laboratory studies which influence contrast thresholds.

Discussion:

Dr. Hulburt asked about the weather conditions which would be encountered at Roscommon.

Dr. Blackwell reported that the CAA Windrose indicated approximately 5% visibility conditions less then one mile. In answer to Dr. Hulburt's question about where the observers would be located, it was reported they they would be stationed on a platform out of doors, protected from the rain by a removable covering.

Dr. Wald commented on the relation of visual thresholds to stimulus distance. He remarked on Freeman's data indicating quite a difference in visual function with viewing distance. He asserted that we should expect differences in visual function for various viewing distances in dim light because of the inadequate and fixed accommodation maintained by at least some observers.

Dr. Blackwell replied that Dr. Wald's findings must mean that visual thresholds will be a function of laboratory viewing distance unless precautions are taken to correct the observer's accommodation at each brightness level used. The implication is that existing visual data must be complicated by factors of accommodation and perhaps fluctuations in convergence which have so far been unquantified.

Mr. Harrison suggested that targets for the Roscommon mission be included at ranges of 200 yards, 300 yards, and 3 miles, if possible. He suggested further that variable size targets might be used instead of variable contrast. He asked whether plans were being made to determine the nature of cover over the ranges used. He also remarked that the line of sight through the atmosphere would be at a slightly inclined angle.

Dr. Blackwell remarked that the vision program was logically completely separated from the problem of atmospheric optics discussed by Dr. Duntley and that factors which influence transmission of light through the atmosphere but had no further effect upon vision need not be measured since measurements of contrast at the eye will be the basic experimental data. Some of the factors suggested by Mr. Harrison probably would not influence visual thresholds except through influence on atmospheric transmission, and for this reason will not be measured variables unless preliminary experiments indicate the necessity for doing so.

FIELD TESTS OF COLORED FILTERS FOR "HAZE-CUTTING".

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Foreword

The field tests reported upon constituted part of the Field Tests of Optical Instruments carried out by the Medical Research Laboratory, U.S.N. Submarine Base, New London, Connecticut, for the Bureau of Ordnance and the Bureau of Medicine and Surgery. Since this problem differed considerably from the studies of optical instruments, the tests were performed quite independently, and are reported upon separately.

The experiment was performed during the first four months of 1946; the process of demobilization did not permit the execution of the full experimental program originally planned.

Summary

As one phase of the field studies of optical equipment, an experiment was performed on the effectiveness of selected neutral and color filters in "cutting haze", that is, in extending the visual range at which targets may be discriminated in the presence of haze by the selective absorption of light of different wavelengths. The results of this experiment show that the use of color or neutral filters does not increase the range at which neutral targets, viewed against a sky background may be discriminated. These findings were made over a relatively short range.

PROBLEM

It has been anticipated by many investigators* that measurable gains in visibility ranges may be obtained in the presence of atmospheric haze by providing the observer with filters whose spectral transmittance is such that light of the shorter wavelengths is absorbed. This is expected since the extent to which light waves are scattered is a function of wavelength. Blue light is more affected by scattering; absorption of the blue by suitable filters should reduce the loss of contrast produced by haze, and so enhance the visibility of targets. This prediction has been amply verified in photography, where films sensitive to the infra-red may be employed, but not in vision, which depends upon the relatively restricted photopic visibility function of the eye.

* For theoretical considerations, the reader is referred to (1) Middleton, W.E.K., Visibility in Meteorology. For a brief review of previous work, (2) Verplanck, W. S. Visual acuity and contrast discrimination through neutral and color filters. Proc. ANOSRDVC, Twelfth Meeting, 12 January, 1945, pp. 71-73.

PROCEDURE

(1) Range: All tests were made over a range 3.43 sea miles in length extending in an north-northeasterly direction from the position of the observers. This short range was the greatest over which experimentation was possible. Targets were placed on the brow of a hill some 300 feet in height; all appeared against an unobstructed sky background. The observation post was located in a classroom of the U.S. Coast Guard Training Station, Avery Point, Conn., at an elevation of approximately 70 feet. The greater part of the range extended over the landing field of NAAF, Groton, Conn.

(2) Targets: The eight targets consisted of wooden frames of dimensions 1.5 x 6.0 feet over which was stretched canvas. Each flat was covered with one of a series of 8 neutral paints, approximately evenly spaced in reflectance. These targets could be oriented in four positions about a pivotal point in the center of each, permitting the discriminations "horizontal" ( ), "vertical" ( ), "left" ( ), and "right" ( ) to be made. In order to keep the targets as consistent as possible, they were repainted at regular intervals with a set of standard neutral paints which had been made up in advance. The reflectance of the eight paints ranged from approximately 20 percent up to approximately 80 percent; no spectrophotometric curves are available. The plane of each target was normal to the direction of the range.

Precise data on reflectance and contrast are not presented. The reflectance of the targets changed with weathering and with the unavoidable accumulation of dirt; it was not possible to repaint them sufficiently often to eliminate this source of error completely. Furthermore, owing to the impossibility of obtaining a properly oriented range and to the requirement of working throughout the day whenever visibility permitted, the light reflected toward the observers from each of the targets changed considerably, and the contrast of each shifted, even though the background illumination remained constant. On sunny days and on overcast days, the contrast altered so much that on some occasions a particular target of the eight appeared in greatest contrast with the sky, and on others, it appeared in least contrast. The result of this effect was that no one target was regularly most or least difficult to discriminate. This is manifest in the results, which showed that the performance on any one target varies widely, but that there are only slight differences among the targets in mean performance.

Filters:

Tests were made on four colored and four neutral gelatin filters, supplied by the Eastman Kodak Company; specifications were checked by measurements made at the U.S. Naval Gun Factory. Significant data, determined for I.C.I. Illuminate "C" are presented in Table IA and B.

The color filters used were chosen in conference with representatives of the Naval Gun Factory to give an approximately equally spaced series with respect to their transmittance curves, and to form, insofar as possible, an evenly spaced series with respect to luminous transmittance when taken with the neutral filters. The adequacy of these series was limited by the selection of filters available.

TABLE IA

Neutral Gelatine Filters Tested

Values calculated for I.C.I. Illuminant "C" from spectral curves obtained with a General Electric Recording Spectrophotometer

Luminous Transmittance	Density	Dominant Wavelength	Purity (o/o)
46.7 o/o	0.33	570.0	4.4
22.9 o/o	0.64	571.5	7.6
10.1 o/o	0.996	570.0	13.0
5.33 o/o	1.27	575.3	15.9

TABLE IB

Colored Filters Tested

Values calculated for I.C.I. Illuminant "C" from spectral curves obtained with a General Electric Recording Spectrophotometer

Wratten Filter Number	Luminous Transmittance	Measured Density	Dominant Wavelength	Purity (o/o)
3	87.8 o/o	0.06	567.0	54.4
12	74.5 o/o	0.13	575.8	98.0
22	35.7 o/o	0.45	595.4	100
29	6.66 o/o	1.18	632.0	100

The test filters themselves were sealed between optical flats in clip-mounts which could readily be fitted over the objectives of the standard $7x50x7^{\circ}$ binocular.

For the tests made on subjects fully adapted to the filter used, an auxiliary set of adaptation filters was provided in mounts designed to slip into the aperture of Polaroid variable-denisty goggle frames.

Visibility Measurement:

The International Daylight Visibility Table was employed in determining visibility, A series of natural targets, subtending angles greater than 0.5° at the observer's eye (viewed with $7x50x7^{\circ}$ binoculars) was selected. These were as dark as it was possible to find, and of varying range. The location and identity of each target was listed on a mimeographed form. At least twice during each morning or afternoon series of observations, a trained recorder checked in turn each of the targets which he was able to see, and the range of the farthest target was taken as V, the Daylight Visual Range. Sets of observations were made within the arbitrary categories of visibility as follows:

(1)	--	none possible
(2) 2.9 to 7.0 miles.	--	observations in afternoon only
(3) 7.1 to 12.0 miles.	--	observations in both morning and afternoon
(4) 12.1 miles plus,	--	" " " " " " " "

Sky Brightness:

Sky brightness was measured with a Macbeth Illuminometer at regular intervals throughout the observation period. All observations were made at sky brightnesses sufficiently high that the use of the most dense filter should produce little or no decrement in performance attributable to the brightness--acuity function. This value was taken as 520 ml.

Observational Procedure:

Standard Runs

Eight subjects observed simultaneously. Each observer was always seated in the same position, and used the same Alidade-Mounted $7x50x7^{\circ}$ binocular, so that the variabilities due to observer, position, and binocular were confounded. Under each condition of visibility, a total of 21 runs was made, in the course of which each observer used the binocular without any filter five times**, and with each of the eight filters of the series twice, according to prearranged schedule. The schedule of filter use was randomized insofar as possible in view of the number of filters to be tested, and the time available for the completion of the experiment.

On each run, the observers recorded the position of each of the eight targets through a series of eight settings of all the targets. Each target appeared twice in each of the four possible positions in each setting. These followed prearranged randomized schedules.

** A greater number of measurements was made with binoculars not equipped with filters in order to increase the reliability of the standard performance.

Thus, a total of 16 x 8 judgments of orientation was made with each of the filters, and 40 x 8 without any filter.

At the end of each of the 8 settings, the correct positions were observed and recorded with the aid of 30x180x 2.25° binocular, so that errors in target positions were impossible and at the end of all 8 settings, the observers corrected their sheets.

In final tabulation of the results, the standard correction for guessing (R - 1/3W) was applied before percentages correct were computed.

The complete set of 21 runs was made under each of five conditions. These were: visibilities 3 and 4 in the forenoon, and visibilities 2, 3 and 4 in the afternoon. All these sets were performed with the observers not visually adapted to the filters; they were in the open room-light immediately before and after the making of each judgment.

Adapted Runs

In a second set of tests, the observers were adapted to the filter being used, since it has been suggested that the effectiveness of a filter might depend on whether or not its user was adapted to it. According to this view, a filter might become less effective after the first few seconds of use, when the retina had become largely adapted to it.

Black cloth hoods were provided which covered the observer's head and shoulders, and from which the objective lens of the binoculars protruded. These shielded the observers from the daylight illumination of the room. Five minutes before the beginning of a run, the observers put on Polaroid goggles fitted with the filter to be used. Immediately before the beginning of the run, the observers placed their heads under the hoods, before taking off the goggles. In this way they were better adapted to the filter. In the "adapted" series, the complete set of runs was made under each of two visibility conditions, visibility 4 in the forenoon, and again in the afternoon.

Results:

Since the contrast of each target altered markedly through the course of a day, and since, consequently, the difficulty of discrimination altered accordingly, data are summarized over all targets. The results, presented in Table II, give the following scores for each filter under each observation condition: $\frac{\text{o/o correct with filter}}{\text{o/o correct without filter}} \times 100$.

There is apparent a slight falling-off of performance with the denser filters, whether neutral or colored. This suggests that these filters brought the background brightness down sufficiently so that the subjects were working in the region of the visual-acuity-illumination function just before the asymptote is reached.

In order to evaluate the significance of the small differences obtained, ε^2 was computed on the data, covering results with the unadapted eye. ε_c^2 proved to be, with respect to the filters - .025, indicating the existence of no statistically significant difference in performance. ε_c^2 with respect to the five visibility conditions was computed as .710, which is significant

well beyond the 1 o/o level. This indicates that the visibility conditions selected led to highly significant differences in performance.

A special ε_c^2 analysis of the data was made for the visibility condition which showed the greatest differences among the performance of filters (3AM). For filters, the value of ε_c^2 was .049, and among the 7 observers on whom data was complete, it equalled .045. There was, then, no significant systematic variation attributable to the use of a particular filter.

No effect is observable which may be attributed to the state of adaptation of the observer to the filters.

These results seem clear-cut. Under the conditions of visibility in which we worked, and at ranges of the order of 3.5 sea miles no difference in performance is shown between colored and neutral filters. Filters as dense as 1.00 log units can be employed without affecting performance. There is evidence that performance is impaired slightly by filters denser than this, but the effect is small, and, again, is independent of the spectral transmission curve of the filter used.

CONCLUSIONS

1. In the discrimination of neutral targets, illuminated by the sun at various angles of incidence, or by an evenly illuminated overcast sky and under a variety of visibility conditions, filters curving off the shortwave end of the spectrum show no effect of "haze-cutting". This result was obtained at a range of some 3.5 sea miles.

2. Filters as dense as 1.00 log units (which reduce sky brightness to 10 o/o of its full value) do not impair performance under any condition of visibility studied. Denser filters, whether neutral or red, may affect performance adversely to a slight extent.

3. These conclusions are valid whether the eye is adapted to the filter or not; there is no indication of a specially favorable effect during the first few seconds of use of a filter.

TABLE II

Performance Score Obtained with Each Filter

Visib. Cond.	FILTERS EMPLOYED (arranged according to density)								
	Without filter	3	12	.33	22	.64	.996	29	1.27
	1. Observers not adapted to filter.								
3 AM	100.0	97.7	95.8	99.8	99.5	103.2	94.8	91.5	97.8
4 AM	100.0	100.9	99.8	99.7	100.1	103.7	97.3	92.9	97.4
2 PM	100.0	102.5	96.6	101.1	98.7	102.5	99.9	94.8	94.4
3 PM	100.0	100.0	99.6	97.5	102.6	94.7	96.7	98.3	96.1
4 PM	100.0	100.1	100.1	101.8	97.8	99.8	96.9	95.0	98.3
	100.0	100.24	98.38	99.98	99.74	100.78	97.12	94.50	96.80
	2. Observers adapted to filter.								
4 AM	100.0	99.5	96.0	97.7	98.0	99.6	96.8	95.6	95.5
4 PM	100.0	98.2	93.6	89.0	98.2	95.8	94.9	94.1	97.3

Discussion:

Dr. Wald asked whether Dr. Verplanck's results indicated no loss in detection even though adaptation brightness was reduced 1 log unit.

Dr. Verplanck stated that this was so and that previously obtained curves of detection would indicate only a small change to be expected through loss of 1 log unit of brightness.

Dr. Verplanck mentioned that the original plan of research had been to include measurements on a dark day in which case reduction of light through neutral or colored filters would have been expected to reduce the range of visual detection.

Dr. Marquis asked whether the subjects reported that they felt they could see better with filters. He asked specifically whether such data could be included in Dr. Verplanck's report.

Dr. Verplanck reported that the observers did indeed report that everything looked sharper, but that systematic data were not obtained and hence were not included in the report.

Dr. Mead expressed satisfaction with Dr. Verplanck's results. He reported that similar experiments conducted at Tufts College indicated that in no case was visual acuity improved by the use of colored filters. He indicated also that observers habitually reported that things looked sharper through the filters.

Professor Hecht reported that similar conclusions were reached by Luckiesh and Moss in a set of experiments some years ago.

Dr. Wald reported that the Luckiesh-Moss data had one interesting feature. The data indicated that eliminating the blue end of the spectrum did not reduce the visual acuity as would be expected. Dr. Wald ventured the thought that if the brightness of a visual task is too great, reduction should be made in the blue end so that the visual function can be maintained at optimal level even though brightness is decreased.

Dr. Verplanck suggested that there might be some advantage in colored filters with long ranges of visibility. He proposed that Dr. Blackwell's group investigate this possibility during the forthcoming experimental program.

Dr. Tousey mentioned that there was one case in which red filters improved visual function although the effect was not produced by increasing so-called "haze penetration". Because of night myopia, using a red filter decreased the chromatic aberration and hence increased the visual acuity.

PHOTOGRAPHIC MEASUREMENTS OF ATMOSPHERIC BOIL*

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Optical shimmer or "boil" effects are most pronounced over bare ground in bright sunshine. These effects demonstrate that the region of the atmosphere near the ground is an optically heterogeneous medium. Rays of light are variously deviated from moment to moment by every portion of this medium through which they pass. The character and extent of such deviations have been measured in the present experiments with the aid of instantaneous photographs of outdoor targets. In each experiment, 30 or more successive exposures have been made and analysed in an effort to determine the instantaneous deviation of any point on the target image from its mean position on a reference scale. It has been found that the average deviation, due to boil, of rays from a point on the target to the camera is in excess of three seconds over level ground in bright sunshine; the maximum deviation may reach nine seconds or more under these conditions. Two separate points on the image are found to suffer the same kind of distortion at the same instant of time if the two points are very close together. The similarity is less marked, however, with points which are farther apart. With points whose separation has an angular subtense at the camera greater than five minutes, the effects of boil upon the two are essentially independent.

INTRODUCTION

The experiments here reported were performed in connection with a project involving research on the design of telescopic reticles. The aim of the experimenters was to supplement the study of reticle patterns with an investigation into the effects of optical shimmer or boil upon the quality of telescopic images in general. In a project report of August 6, 1945[1] the authors presented the results of this investigation, together with some preliminary considerations of the relation of boil to the performance of stereoscopic rangefinders.

The present experiments employed a photographic method of studying the quality of image in a telescopic system under various atmospheric conditions. The method consisted basically of forming a real image of a distant, outdoor target on a photographic film and making enlarged prints of the film for later study.

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* The work described in this report was carried out under a contract between the Office of Scientific Research and Development and Brown University. A first public report of this work was presented at the Winter Meeting of the Optical Society of America, February 20-22, 1947, New York, N. Y.

** Now at Columbia University, New York, N. Y.

*** Now at the University of Wisconsin, Madison, Wisconsin.

1 "Photographic Measurements of Atmospheric 'Boil' with some Preliminary Theoretical Considerations of the Relation of 'Boil' to Rangefinder Magnification and Baselength." Division 7, N.D.R.C.

A photographic method was used by A. E. Douglass[2] in 1926 to record the appearance of shadow bands caused by atmospheric refraction. His method differs from our own, however, in using a point source of light and recording an image of a portion of the atmosphere directly on a photographic plate. Douglass' method shows the phenomenon of atmospheric refraction as causing light and dark bands of varying density, while our method shows the same phenomenon as a distortion of the image of a target.

The influence of atmospheric distortion on the precision of telescope pointing has been studied in experiments reported by Washer and Williams[3]. These investigators have shown that the probable error, E, of a single pointing is of the order of 0.62 second using a magnification of 37 diameters, "under average daylight conditions and over a terrain that consists partly of park area and partly of city residential and business section".[4] The value of 0.62 second is contrasted with a value of approximately 0.24 second for E when indoor targets are used. The authors attribute the difficulty of outdoor observations to the fact that the observer must set the cross-hairs into apparent coincidence with a constantly oscillating image of the target.

Less directly related to our experiments are studies of loss of contrast or detectability in a target seen through haze or fog. Hulburt[4] has analysed the influence of atmospheric haze in terms of the scattering of light measured by means of a telescopic photometer; and Hardy[5] has shown the extent to which atmospheric haze may reduce the effectiveness of telescopic observation.

PROCEDURE

Basically, the procedure consisted of photographing a black-and-white line target located outdoors at a distance of several hundred meters from the camera, and measuring on the photographs the amount of image distortion which could be attributed to shimmer or boil. It was found necessary to have a reference scale, similar in function to a telescopic reticle or set of cross-hairs, in order to determine the absolute magnitude of the deviation of an image point from moment to moment. For this purpose a linear scale was set up at a distance of about 100 meters from the camera in such a way that it was imaged alongside the target on the photographs. The advantage of the scale over a reticle was that any slight vibration or displacement of the camera would affect equally the images of the scale and the target, and hence cause no serious error in measurements of the deviations of the latter. We are reasonably confident, therefore, that the deviations reported below, after due allowance has been made for error in measuring the photographs, are due solely to atmospheric effects.

Figure 1 shows in diagrammatic form the positions of the target, scale and camera. Also shown is the position of a railroad tunnel which was used in some of the experiments to minimize the effects of boil on the reference scale by shielding from direct sunlight the space between it and the camera.

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2 Douglass, A.E. Photpgraph of shadow bands. Astrophysical J., 63 (1926), Plate XI a following page 188.

3 Washer, F.E. and Williams, H.B., J. Opt. Soc. Am. 36, 400 (1946).
4 Hulburt, E. O., J. Opt Soc. Am. 31, 467 (1941).
5 Hardy, A. C., J. Opt. Soc. Am. 36, 283 (1946).

In each experiment, about 30 successive photographs were made of the target and scale. The camera consisted of a specially adapted telescope objective[6] having a focal length of 128 cm. The aperture was stopped down to a diameter of 2.9 cm. in order to secure the depth of focus necessary to include both the target and the scale. Agfa Supreme roll film was used, with exposures of 0.04 second.

The preliminary experiments were conducted at an average height of about 12 meters above a predominantly grassy terrain at the Brown University Stadium. Later experiments were done over a railroad right-of-way with no track at Riverside, R.I. In all of the final experiments the camera and scale were set up within the railroad tunnel and the target posts were photographed over a region of railroad right-of-way which was open to direct sunshine. In both the Riverside and the tunnel locations a high degree of boil was assured by working at an average height of about 75 cm. above the surface of the bare ground.

RESULTS

Enlarged photographic prints were made from all film records obtained by the procedure above described. Figure 2 shows samples of such prints, in which the effects of boil are seen to include a typical wavy and blurred appearance of all contours and a shift, from moment to moment, of any point on the target with reference to a corresponding point on the scale.

The amounts of shimmer present under the conditions of these experiments have been determined, by measuring, on each photographic print, the instantaneous position of a given point on the target with reference to the scale. A frequency distribution of such scale positions is shown in Figure 3 for one target line in the experiment of June 19, 1945, on which day there was a fairly large amount of shimmer. The average deviation of single measurements from the mean (denoted by the vertical line) of this distribution is 2.39 seconds of arc. Average deviations in excess of three seconds have been obtained for experiments in which the effects of boil were even more pronounced.

A quantitative approach to the problem of image distortion has been undertaken in the following manner: The image is said to be undistorted (a) if all parts of it remain stationary with respect to the reference scale, or (b) if all parts undergo the same displacement at the same instant with respect to the scale. The degree of distortion is then defined as the degree to which one point on the image is shifted differentially with respect to another point at any given instant of time. Obviously it is this differential shift of separate parts of the image which produces the wavy or warped appearance of a telescopic target in the presence of boil.

We have applied this type of analysis to records such as those appearing in Figure 2, and arrive at the following conclusion: When a target post in one region of the scale has been shifted by a certain amount[7] along the scale in

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6. The telescope was borrowed from the Department of Astronomy at Brown University through the courtesy of Professor Charles H. Smiley.

7. It is assumed here that the shifts from moment to moment are of a "random" nature and that the "true" or undistorted position of the target post is approximately indicated by the mean position as measured on a set of 30 or more photographs.

one direction, it is likely that the post immediately adjacent to it will show a similar degree of shift in the same direction at the same instant of time. It is less likely, however, that posts more remote from the original one will be similarly shifted; in fact, for posts separated by more than 200 or 300 seconds from one another there appears to be no appreciable relationship between the instantaneous shift of one and that of the other.

Figure 4 presents some samples of the evidence for the above statements. If we call m the algebraic difference between shifts of a given pair of vertical posts at a given instant, we may plot the average value of m for 30 or more photographs as a function of the separation between the posts (angular subtense at the camera). The data of Figure 4, A show that when no boil is present (weather completely overcast) there is no relationship of the sort described above. In 4, B and 4, D however, it is seen that m is diminished for separations of less than 200 seconds of arc, as compared to a value of about 3.7 seconds for greater separations when a considerable amount of boil is present. With the very large amount of boil in Figure 4, E m attains a value of about 4.5 seconds.

The value of m as measured here is inflated to some extent by errors of measurement, which are inevitably large as a result of the blurred appearance of the telescopic image. The magnitude of this factor has been determined by making the usual measurements of m on a series of 40 records, 10 of which were identical enlargements from the same original negative. In these 10 control records, not identified as such by the person making the measurements, the value of m should logically be zero; the values obtained by measurement are shown in Figure 4, C. It is concluded that the average error, e, of measurements of m is of the order of 1.2 seconds; and that the average amount of distortion or differential shift, d, is related to m approximately by the relation

$$d = (m^2 - e^2)^{\frac{1}{2}} \qquad (1)$$

if we assume that m and e are normally distributed. For separations greater than 300 seconds, d has a value of about 3.5 seconds under the conditions of May 12 and June 19, 1945, when a large amount of boil was present (see Figure 4). For experiments such as that of May 10, 1945, when boil was not present to any appreciable extent, d has a value of less than 1.5 seconds regardless of the separation between points. With the very pronounced boil of June 25, 1945, the value of d reaches about 4.3 seconds.

All of the measurements reported above have been in terms of displacements whose angular subtense was measured at the camera in a horizontal plane. That similar vertical displacements are also found is shown by the distortion of the grid pattern of Figure 2, H and I. Over the limited area of this surface, 68 minutes square, the character and degree of boil effect are not noticeably different whether horizontally or vertically measured. It seems probably that this situation holds only of a target which is sufficiently small so as not to extend vertically through strata of air whose densities are dependent upon their heights above the ground.

DISCUSSION

The present investigation has shown, by the use of an objective photographic method, the average amount of distortion present in a telescopic image under various degrees of boil or shimmer. Such atmospheric effects are presumably similar to those which would be expected of a set of hypothetical

prisms such as the one shown by the dotted lines at P in Figure 1. The prisms, which occupy the space between the scale and the target, are to be thought of as having constantly changing power, orientation and size. It is apparent that the effect of any prism is to produce a deviation in the direction of rays entering the camera from any point on the target. The appearance of boil results from the "random" summation of such deviations from instant to instant, and from point to point on the target.

Presumably an observer, in pointing a telescope at a target, must perform a sort of visual integration whereby the telescope cross-hair is brought into coincidence with the mean apparent position of a target point as represented by the vertical line in Figure 3. The exact relation between the amount of distortion as we have measured it, and error of pointing as measured by Washer and Williams, has not yet been determined under comparable conditions of boil. In our experiments, the mean displacement of the target image from its "true" (i.e., mean) position appears to be in excess of three seconds; and the whole extent of the oscillation may be about 18 seconds under conditions when the boil effect is large. Certainly the probable error of a single pointing of a telescope under these conditions would be greatly in excess of the 0.62 second reported by Washer and Williams for an air path which was high above the ground. Furthermore, in our experiments it was not feasible to measure the effects of the atmosphere intervening between the telescopic camera and the scale. Only a direct comparison of observer performance with photographic records made under the same conditions would reveal the exact correspondence between the subjective error and the objectively measured oscillations.

With regard to rangefinder performance, our experiments indicate that atmospheric disturbances affecting the two lines of sight to the instrument may be considered to be independent of one another except for the region near the target on which the two lines are converging. The nature of vernier or stereoscopic observation is such, however, that we should hesitate to predict that a given amount of distortion would lead to a certain error of ranging. A "visual integration" must also be involved in establishing a stereoscopic or vernier form of contact with a target image consisting of two independently oscillating units. Nevertheless, an analysis of the situation existing at a given moment may be of interest.

The standard equation for the error, E, of ranging under ideal conditions of visibility is [8]

$$E = \frac{fR^2}{206{,}000bM} \tag{2}$$

where f is the variability of observing and R is the range, b the base-length and M the magnification. E, R and b are all expressed in the same units of length (e.g., meters) and f is in seconds of arc. It may be assumed that optical boil contributes a variability factor, g, to the observer's variability, and that this contribution is proportional to the magnification. The error equation then becomes

$$E = R^2 \, [f^2 + (gM)^2]^{\frac{1}{2}} \tag{3}$$

8 Gleichen, A. The theory of modern optical instruments (translated by H. H. Ensley and W. Swaine) 1918, London: His Majesty's Stationery Office, xii 376.

For large values of g and M,

$$[f^2 + (gM)^2]^{\frac{1}{2}} \sim (g^2M^2)^{\frac{1}{2}} = gM \qquad (4)$$

and

$$E = \frac{R^2g}{206,000b} \qquad (5)$$

Equation (5) means that, when a large degree of optical boil is present, magnification has no influence on the error of ranging conceptually regarded as existing for a given instant of time. What influence these instantaneous errors might have on rangefinding might be answered by an experiment in which photographic analysis is coupled with simultaneous operator performance over the interval of time taken in making range settings.

Discussion:

Professor Hecht remarked that Dr. Riggs' data were presented in terms of angular subtense. He asked what the physical magnitude of the turbulent area was.

Dr. Riggs reported that the experiment was not particularly adequate to define the physical size of the turbulent areas since it was difficult to localize turbulence at any one point. He estimated that turbulent areas might be several inches in diameter. This order of magnitude is in agreement with data reported by the astronomer, Douglas.

Dr. Tousey mentioned that there is a variation in intensity of a point source because of atmospheric boil which can be observed in the twinkling of stars.

Mr. Douglas reported that variations in intensity are often as great as 2 to 1.

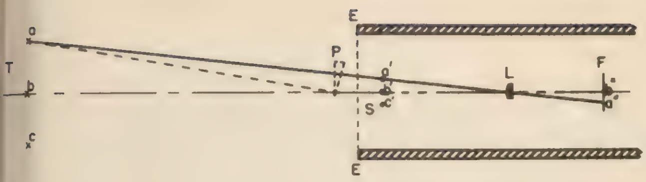


FIGURE 1. Diagram showing relative locations of target, scale, camera lens, film, and entrance to tunnel.

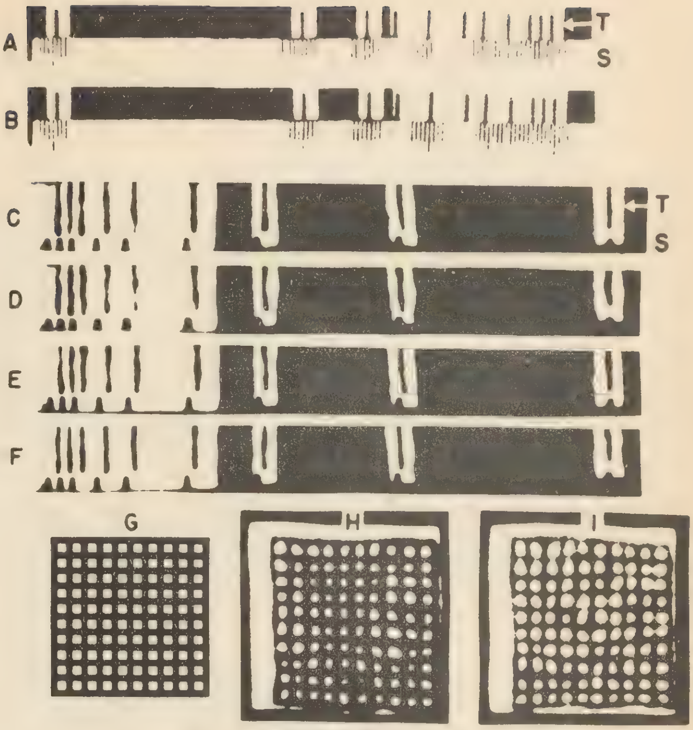


FIGURE 2. Image distortion due to atmospheric boil

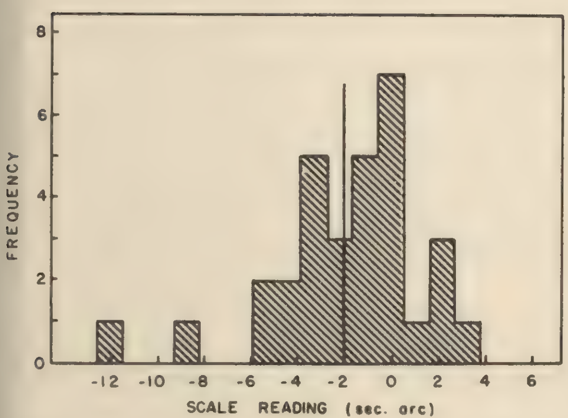


FIGURE 3. A frequency distribution of 31 measured positions of a shimmering image of the target. Experiment of June 19, 1945.

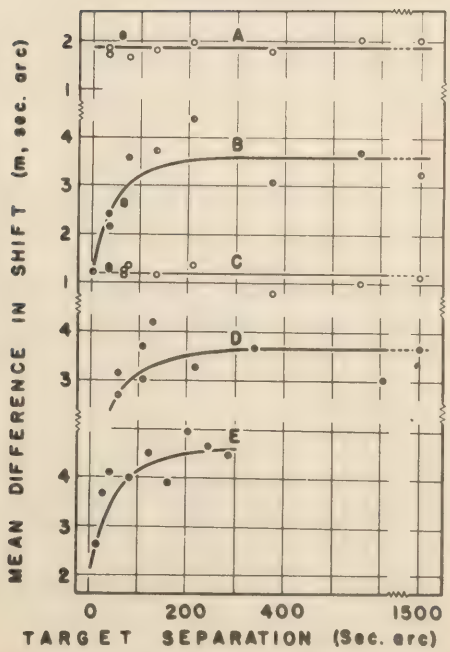


FIGURE 4. Differential shift, m, due to atmospheric boil

VISIBILITY CONDITIONS IN POLAR REGIONS

Dayton R.E. Brown, Comdr., USNR

The light, weather, and inherent contrast conditions of any region largely determine its visibility. This paper discusses weather and contrast very briefly. But since the daily altitudes of the sun, throughout the year, are peculiar to the latitude alone, I should like to explain, as completely as my time allows, the habits of the sun, 75° from the Equator. Also I should like to discuss light values for selected days throughout the year, associated with the sun's positions. Arctic light is somewhat restricted over a year's time; exceedingly restricted for any one day. It never gets as light nor as dark at N. Devon Island, 75° N, as it does here in the United States.

Light conditions in the Polar Regions are also peculiar to those regions. This becomes axiomatic when one remembers the peculiar path the sun takes up there. It goes more around the horizon than up and over and down. Let me briefly review this.

Plate 1, line 1. During the course of the year, the earth goes around the sun so that in summer the North Pole inclines toward the sun, in winter inclines away from it, and on or about March 21st and September 23rd the poles do not incline one way or the other to the sun but are perpendicular to the light rays. The same four positions of the earth relative to the sun's rays are shown on a larger scale on line 2. These diagrams also show the Arctic and Antarctic Circles, the Tropics of Capricorn and Cancer, the Equator, and two points L and L′. L′ is a point on the earth's surface 75° North Latitude, Devon Island, at apparent noon. Twelve hours later the earth has turned around on the polar axis so that Devon Island appears at L at midnight.

On the next line of diagrams lines SN and N′S′ represent the horizons at Devon Island: SN the midnight horizons, N′S′ the noon horizons. The positions of the sun relative to these horizons are shown for the 21st days of June, March, September, and December, for noon and for midnight. The altitudes are A′ and A respectively.

The diagrams at the bottom of the page show side views of the sun's path relative to the North-South horizon - same place and dates.

On the diagrams of Plate 2, the altitudes are shown as before, and also developed at the side, as a function of time. The dotted lines have been added to show how these altitudes at Devon Island compare with the altitudes of Washington, D. C., latitude 39° North.

The diagrams of plate 3 again are for Devon Island (or for any other place 75° N or 75° South for that matter except that for South Latitude, the time of the year would have to be shifted over about 6 months). The top figure shows the sun's daily mean variation in altitude for June 21st, and for December 21st. All other days have similar curves and fall between the two curves shown.

The lower diagram of Plate 3 illustrates the change in the light condition for clear days, from noon to midnight the 21st day of each month for the 12 consecutive months, starting with March.

At the side of the lower diagram, column I gives a scale in 10 degree intervals of altitude. Columns III and IV give an approximation of the magnitudes of foot candle illumination on a horizontal surface: Column III for clear days and nights; Column IV for overcast from 10^{-6} to 10^{4}. Column II represents in a conventional form the variation in the brightness of a white blotter exposed to the illumination shown in Column III. Both of these diagrams are sort of idealistic since no correction has been made on them for moonlight or the effects of weather.

It seems to me that the most significant fact resulting from this round-and-round path of the sun, is the small and gradual change in illumination that can take place during the course of any one day and which is particularly small on certain days. The yearly change is comparatively small also. The total spread in the sun's altitude at Devon Island is about 77° over one year's time. At Washington, D. C., it is 102° in 24 hours. The change in illumination over a whole year on Devon Island is less than the change which may occur in one (24 hour) day here in Washington. And what light changes do occur are noticeably much more gradual in the Arctic.

All of the curves on the diagrams are drawn to show where the center of the sun's disk is at the altitude indicated. Some of the curves cross the horizon lines at specific hours. These hours are not the accepted hours of sunrise or sunset. This apparent inconsistency is due to the fact that sunrise and sunset are defined to occur when the upper edge of the disk of the sun appears to be exactly on the horizon. Accepting this definition, 16 minutes of arc for the sun's semi-diameter, and 34 minutes of arc for refraction, have been allowed for in the compilation of sunrise and sunset tables. From here on this paper takes this accepted definition. Here are a few more interesting figures for Devon Island. For 108 days the sun stays continuously above the horizon, but never higher than 38.5°. During this period the light never gets much above 7,000. foot candles nor much below 10 foot candles. On many days there is no perceptible change in the light at all. For 162 days we have both sunrise and sunset. On one day, about April 28th, the sun rises but doesn't set. One day it sets but doesn't rise (August 15, 1946, since it's been up since April 28th.)

During the 162 days of both sunrise and sunset, the sun averages 15° from the horizon but is never more than 30° from the horizon, above or below. For 70 of these sunrise-sunset days, the sun may vary into 8 orders of light magnitude; for 32 days into 7 orders; for 30 days into 6 orders; and for 32 days into 5 orders.

The first and last 20 or 21 days that the sun stays below the horizon, the light variation may be into 3, 4, or 5 orders of magnitude, and for the other 52 days that it stays below, the light ranges from 10^{-3} to 10^{-4} f.c., only 2 orders.

When the sun stays above the horizon - 108 days - the variation is a maximum of 4 and generally is only 1, 2 or 3 orders of light magnitude.

The light condition which is commonly referred to as twilight extends, according to the definition, from the time the center of the sun's disk is 50 minutes of arc below the horizon to the time it is 18 degrees below, either before sunrise or after sunset. At the moment the center of the sun's disk is -18°, the condition is called Astronomical Twilight. Here in Washington,

D. C., this twilight period lasts from one hour and a half to two hours. On Devon Island, from an hour and a half to six hours and forty-two minutes. Of course, the boys on Devon Island are pikers too. At the Pole, only 900 miles farther North, there is only one sunrise a year, but it lasts for about 50 days.

I don't know much about weather! Certainly I'm no meteorologist, so I'll just hit some high spots effecting visibility.

Even the thinnest veil of cirrus or stratus cloud passing between the sun and an object on the earth cuts down the total illumination on that object. This may effect the contrast and hence the visibility of the object. For example, if the object was darker than its surround before the veil came between it and the sun, the contrast is apt to be increased and the visibility of the object thereby increased. If the object was brighter than its background before, the converse is most likely to occur.

The variation in light and the light intensities themselves that I discussed earlier for various periods of time are modified and further limited by fog, rain, snow, or any cloud condition of 0.3 or more, and, of course, by the moon.

Fog is quite common in the summer months in the Polar Regions, especially in the Arctic where there is so much coastal area, or water area.

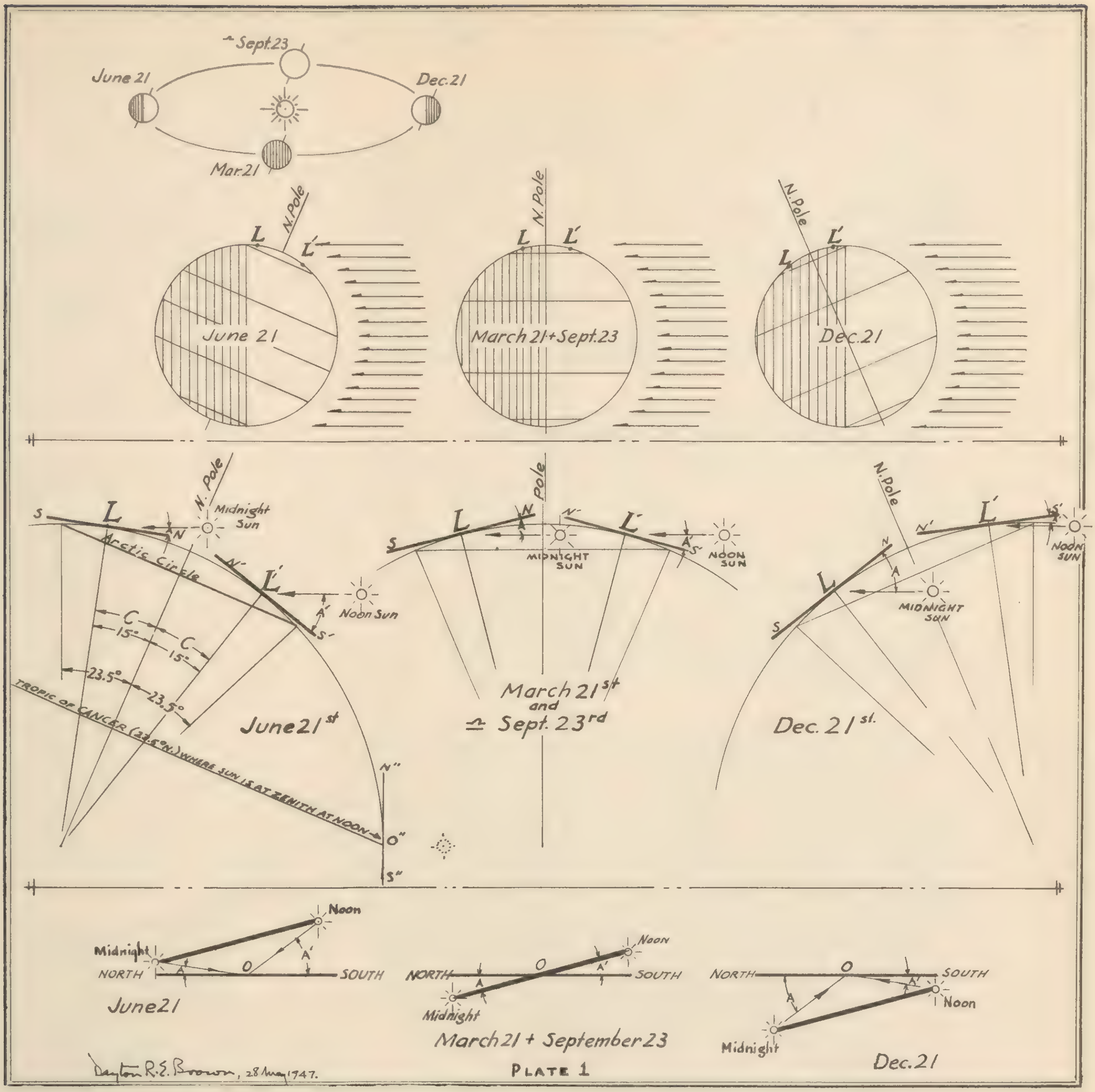
During a large portion of the year, ice covers the sea, and snow blankets the land. In these periods, contrasts are often so low that visibility is reduced to almost nothing. Steffanson told of reducing the danger of falling into a crevasse, as he walked along, by throwing a black piece of wood a few feet ahead.

A light wind, 15 knots or even less, will raise snow high enough to obscure the ground and small objects; over 15 knots drifting snow obscures huts or tents which might otherwise be seen. And, of course, falling snow may do the same.

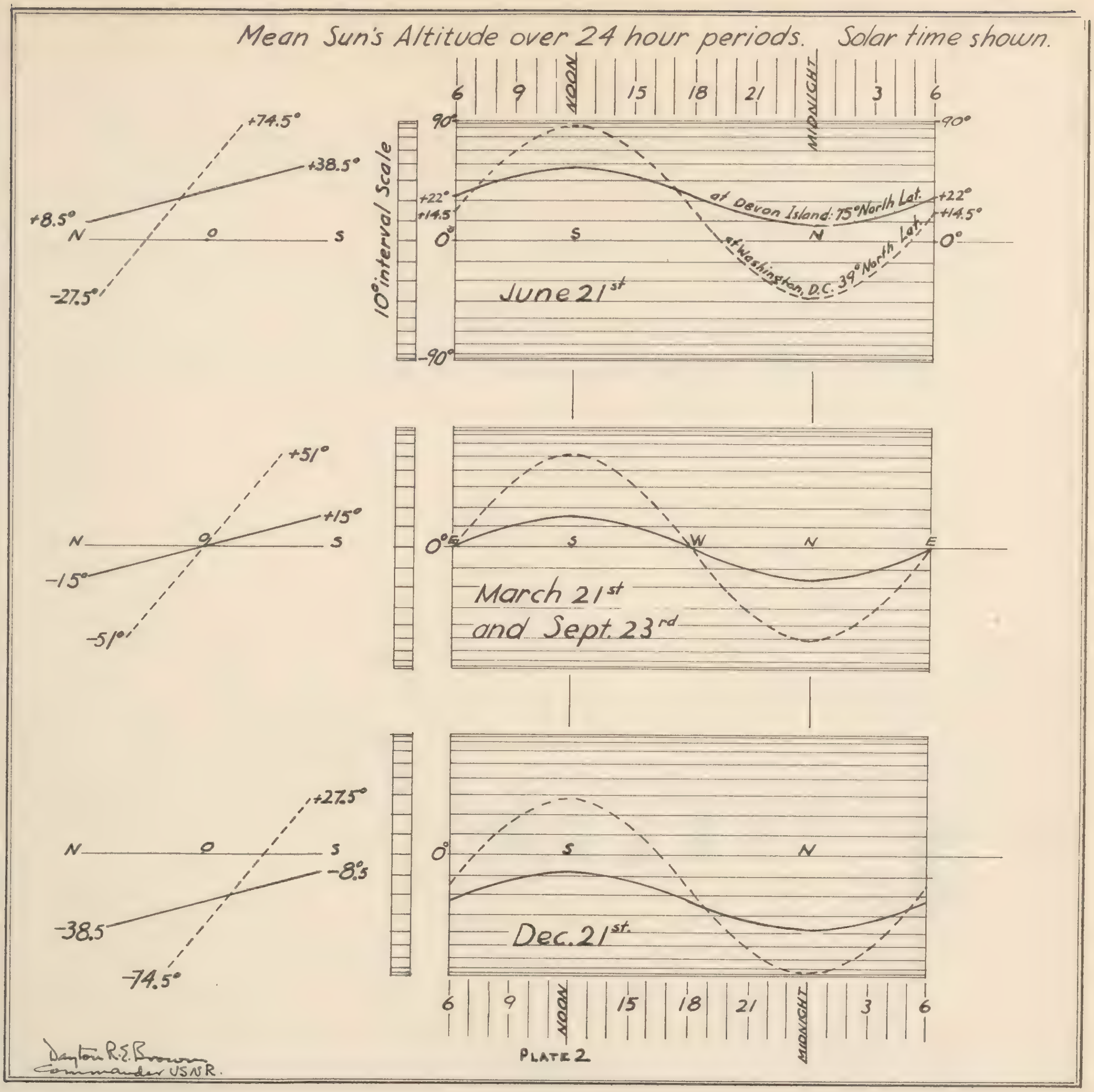
On the other hand the Arctic Regions can be very clear indeed, for Polar air is exceedingly transparent when anticyclonic conditions prevail. (i.e. High pressure areas.)

Clear air and strong contrasts such as a dark mountain rising above white sunlit snow make for extreme visibility. Ranges of more than 100 miles are not uncommon. Under such conditions visibility to the horizon is only limited by the contrasts and the altitudes from which they are viewed.

I have 15 of my Arctic paintings here. Visibility data are available for most of them. The paintings attempt to illustrate the visibility conditions and to give a more complete picture of the country, the light, and the weather, than I can describe with words. I trust that the paintings may also give a glimpse into the beauty of this strange and wonderful land.



Sept.23
June 21
Dec.21
Mar.21
N. Pole
L
L'
June 21
March 21+Sept.23
Dec.21
S
N
Midnight Sun
Arctic Circle
N'
S'
A'
Noon Sun
C
15°
23.5°
TROPIC OF CANCER (23.5°N.) WHERE SUN IS AT ZENITH AT NOON
June 21st
N"
O"
S"
MIDNIGHT SUN
NOON SUN
March 21st and Sept. 23rd
MIDNIGHT SUN
NOON SUN
Dec. 21st.
Noon
Midnight
NORTH
SOUTH
O
A
June 21
Midnight
March 21 + September 23
Noon
Dec. 21
Dayton R. E. Brown, 28 May 1947.
PLATE 1



Mean Sun's Altitude over 24 hour periods. Solar time shown.
10° interval Scale
June 21st
at Devon Island: 75° North Lat.
at Washington, D.C. 39° North Lat.
March 21st
and Sept. 23rd
Dec. 21st.
NOON
MIDNIGHT
Dayton R. E. Brown
Commander USNR.

PLATE 2

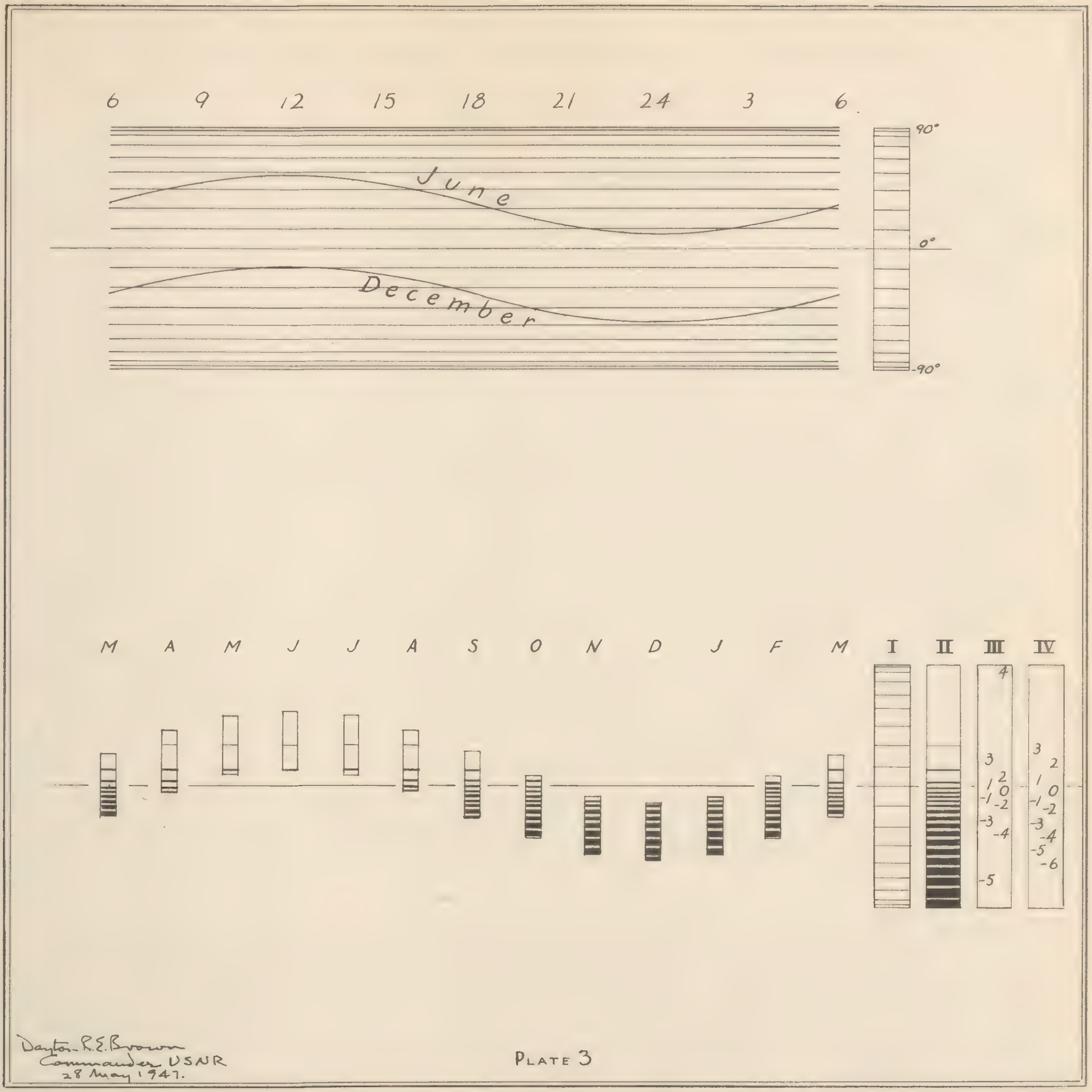

6 9 12 15 18 21 24 3 6
June
December
90°
0°
-90°
M A M J J A S O N D J F M
I II III IV
4
3 2 1 0 -1 -2 -3 -4 -5
3 2 1 0 -1 -2 -3 -4 -5 -6
Dayton R. E. Brown
Commander USNR
28 May 1947.

PLATE 3

THE PENNSYLVANIA STATE COLLEGE ATMOSPHERIC OPTICS PROGRAM

S. Q. Duntley

In connection with the evaluation of the performance of optical instruments by means of the Tiffany nomographs, it has been deemed necessary to verify the law of atmospheric optics which is built into those charts. This law, sometimes credited to Koschmeider, states that the contrast of any object seen against a background of horizon sky is exponentially attenuated with distance. Experimental verification of this law appears to have been conducted almost exclusively with targets darker than their background, and for this case the validity of the law has been demonstrated by a number of different investigators, although the precision of their experiments leaves something to be desired. A small amount of experimental data was obtained at the Tiffany Foundation using targets lighter than their background. These data indicate gross departures from the Koschmeider law when the inherent contrast of the targets was five or more. These departures were never satisfactorily explained, but because of the small quantity of the data they have not been given serious attention. It now seems advisable to repeat the Tiffany experiments with better technique and equipment, and to explore the reduction of apparent contrast by the atmosphere under all circumstances of military interest. Impetus has been given to this research by a yet unpublished theory of atmospheric optics which has been developed by the author during the past year. This analysis shows the Koschmeider law to be a special case of a more general principle, the simple exponential law relating only to objects of low inherent contrast. It appears that a target of contrast unity might be expected to obey the Koschmeider law to a useful degree, but that high contrast targets would be expected to deviate in a manner similar to that shown by the Tiffany observations. It is intended that the experiments at the Pennsylvania State College will provide data for checking this theory.

The preparations which are now in progress include the construction of high precision photoelectric photometric equipment and the construction of billboard-type targets at ranges up to ten thousand yards on the grounds of the Pennsylvania State College. Data of high precision will be taken under carefully observed meteorological conditions. This will be supplemented by additional data over longer ranges which will be taken in connection with the University of Michigan visibility program.

Preliminary experiments have been made on a new type of visibility meter. This instrument measures the ratio of the apparent brightness of two black boxes at unequal distances along the same path of sight. Preliminary explorations of this type of attenuation meter will be made with the photoelectric equipment now under construction. Later a refined instrument capable of giving a direct record of meteorological range as a function of time may be constructed using standard parts from a General Electric recording spectrophotometer. Preliminary tests of this equipment have already been made at G.E. and successful operation was achieved down to and including twilight levels.

Discussion:

Mr. Harrison remarked that studies by Kaschmeider indicated that with a white object contrast reduction by the atmosphere is a function of azimuth.

Dr. Duntley indicated that it might be desirable at a later date to conduct sufficiently large-scale measurements to determine whether the variation in reduction as a function of azimuth would exist.

Mr. Harrison remarked that at extremely short ranges Kaschmeider's formula would not be expected to exist, and asked Dr. Duntley whether it was anticipated that measurements would be made through fog.

Dr. Duntley remarked that it was the plan of the research to "learn to walk before trying to run". Measurements will be made under clear atmospheric conditions to explore techniques and methods of reporting prior to exploring fog.

Mr. Harrison remarked that variable clouds along the air path will produce variations in conditions.

Dr. Duntley remarked that measurements of luminous intensity will be made at frequent points along the line of sight to evaluate this variable.

VISUAL PROBLEM RELATING TO THE
RELATIVE EFFICIENCY OF MONOCULAR AND
BINOCULAR OPTICAL INSTRUMENTS

John E. Darr

A military requirement has been expressed by the using services of the Army for a hand held five power periscope of some thirty inches in length. The reported research of the past few years having indicated an appreciable advantage in favor of binocular vision over monocular vision for resolution and for detection of low visibility targets as well as for reduction in fatigue, it has been recommended that a binocular eyepiece be used to divide the light from a single objective so that binocular vision may be attained. Since the light reaching one eye will be less than fifty percent in total flux of that which would be available from a single eyepiece, this design is considered questionable. An analogous situation might be produced by comparing the effectiveness of one side of a pair of binoculars with that of the whole binocular fitted with a strictly neutral filter of fifty percent transmission. The question then is whether binocular vision is really worth while if one hundred arbitrary units of light entering are divided into forty units for left eye, forty units for right eye and twenty units for internal losses whereas the monocular system will supply better than eighty units to the one eye.

ABSTRACT OF DR. LORRIN A. RIGGS'

SUMMARY OF INFORMATION ON RELATIVE EFFICIENCY OF MONOCULAR AND BINOCULAR OPTICAL INSTRUMENTS

Available experimental evidence indicates that binocular observation is superior to monocular for picking up targets under adverse conditions of observation. There is, however, no general agreement on the extent of this superiority; values ranging from 10 percent to 50 percent have been reported in various investigations. Nor is there any common agreement on explanations for the superiority of binocular viewing.

Experimental evidence: At Brown University, Miller and Beck have made perhaps the most directly relevant observations for the present problem. They have made an extensive series of experiments on the ability of observers to pick up a target under low levels of illumination.[1] The target consisted of a stationary spot projected onto a screen. Monocular and binocular observations were made with various models of binocular telescope as well as with the unaided eyes. They found, briefly, that the location of targets could always be detected binocularly at ranges which were 12 to 15 percent greater than for the corresponding monocular observations. Under certain conditions the superiority of binocular ranges reached 25 percent. This study is particularly significant because (1) it involved the task of search and detection, (2) natural pupils were used, with a minimum of constraint upon the observer, (3) a satisfactory number of psychophysical determinations were involved, and (4) telescopic viewing was provided.

A brief, unpublished experiment has recently come to my attention in which two observers were used to pick up outdoor targets. One of the observers, Mr. E.P. Johnson, happens now to be one of my graduate students. He states that in this experiment, done for the RCAF, targets could be picked up binocularly with a certain percentage of success at a certain low level of brightness. For monocular pick-ups, the brightness level had to be raised by about 50 percent to reach the same percentage of success. Mr. Johnson also reports that a control subject with a strong heterophoria showed no such superiority in binocular observations. This subject failed to maintain binocular fusion at the low brightness levels used here. It is Johnson's belief that binocular fusion is a necessary feature of maximum efficiency of detection.

Crozier and Holway[2] have found that the absolute thresholds for monocular and binocular vision are in the ratio of 1.4 to 1, and that a similar ratio exists in the case of the discrimination of brightnesses where the size of pupil is held constant. Several other laboratory investigations may be mentioned, but their applicability here may be questioned because they have not

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1 Miller, C.W. & Beck, L. Effect of design of binoculars on the problem of detection of targets under low levels of illumination. NDRC Report, Brown University, 1945.

2 Crozier, W.J. & Holway, A.H. J. gen. Physiol., 1938-39, 22, 341-364; 1939-40, 23, 101-147.

involved the actual task of picking up a target. Among these are the studies of Fry and Bartley[3] on the brilliance of objects seen binocularly, those of Crawford[4] on ocular interaction, and those of Pirenne[5] on binocular and monocular thresholds. In all of these investigations a definite superiority of binocular vision was shown.

Some explanations: Some interpretations of binocular superiority are the following: (a) Lithgow and Phillips[6] attribute it to the fact that twice as much retinal area is stimulated when two eyes are used as when only one eye is active. Doubling the area of stimulation of one eye would thus have essentially the same effect. (b) Crawford (loc. cit.) believes that the above factor may be important, but does not account for all of the observed effects. He stresses also the greater discomfort and fatigue of monocular viewing. (c) An additional factor of increased probability of detection is also mentioned by Crawford for the case where two eyes are functioning with individual variations of sensitivity from time to time. (d) The probability explanation is further elaborated by Pirenne (loc. cit.), who assumes that when either of two eyes absorbs the minimum number of light quanta for stimulation, the observer reports seeing the light. The probability of seeing the flash is greater with two eyes than with one, and by an amount which agrees with Pirenne's experimental data on the seeing of short flashes. This would be true even if the two eyes belonged to different observers. (d) Crozier and Holway, on the other hand, believe that there is a specific summation in the higher visual centers. Several other investigators also incline to this view. The large loss in illumination which must be tolerated if binocular vision is to be used must be considered. It is possible that the gain obtained with binocular vision, in comparison to monocular, is not enough to compensate for the loss in illumination. It would seem feasible, however, to set up the apparatus you intend to use and see whether 40 percent reduction does indeed give worse performance in spite of the binocular vision.

Discussion:

Dr. Verplanck remarked about a German U-Boat periscope he examined while on duty at the New London Submarine Base. This periscope was of the general type contemplated by Mr. Darr in which the light from the objective was divided in order to provide binocular viewing. The German periscope appeared to have a lot of advantages over a monocular periscope. It had tremendous depth, and field tests indicated a gain of 10 percent in range. The day-light advantage of binocular vision is about 2 percent in range and the 40 percent loss in illumination level is certainly negligible under daylight conditions. Subjectively, everyone prefers binocular vision. In the evaluation of binocular instruments in the New London field tests, every man tested expressed preference for instruments with which he could use both eyes. Research done by Hyde, Cobb, Johnson, and Weniger during the first world war indicated the advantages of using binoculars in the daytime by increasing the speed with which a target could be located.

3 Fry, G.A. & Bartley, S.H. Amer. J. Ophthal. 1933, 16, 687-693.

4 Crawford, B. H. Proc. Roy. Soc., 1939-40, 128B, 552-559.

5 Pirenne, M. H. Nature, 1943, 152, 698-699.

6 Lithgow, R.J. & Phillips, 1938., J. Physiol., 91, 427.

VISUAL PROBLEM RELATING TO THE
LIGHTING OF WORKING SURFACES

John E. Darr

In the process of developing certain vital artillery fire control and target acquisition equipment it has been found that visual accommodation to a great variety of levels of illumination ordinarily is required of the operators of the instruments. Even though much of this equipment is highly automatic the efficiency of the operator often limits the ultimate effectiveness of the system. It is therefore important that any possible improvements in the physiological and psychological situation be obtained. In a plotting room under general illumination some operators will be required to perform consecutively such varied visual tasks as reading meters and scales, matching or measuring traces on oscilloscope screens, and tracking obscure targets against day dusk or night skies and over water. Others will be required to observe the actions and check settings of these operators, refer to printed matter and to maps and to move freely within the room. It is believed that the extreme contrasts associated with the usual black crackle surfaces and projected illumination combined with chromium plated surfaces and brightly colored signal lights, creates eyestrain, fatigue and impaired visibility to an extent intolerable to the required degree of alertness, judgment and continued high performance. While dark adapted vision will be required occasionally in night tracking its use will probably be so limited that special provisions such as individual hoods might be used. The major parts of the question, as affects design, are the determination of the optimum brightness for general illumination, the color of backgrounds, the amount of color and shade contrast in the objects under scrutiny, and the brightness of separately illuminated objects. It has been suggested that blackout illumination be provided at a very low level of white light and that flat white be used on all background and surrounding surfaces. Another suggestion is that pastel green, gray or blue be used on the painted surfaces. The choice of background color, its degree of reflectance, the color and brightness of illumination and the degree of color and shade contrast in the indicators is thrown on the table for discussion as requiring study for the determination of the illumination specifications for the development of this sort of fire control materiel.

ILLUMINATING THE TASK

by C. L. Crouch*

Illumination has been thought of as both an engineering subject and an art -- an application of engineering as to control of light, an art as to the visual effect produced, or more precisely, the psycho-physical reactions. As a group, our engineers attempt to fulfill the following definition of good illumination.

> "Illumination is good when it is suitable in quality and quantity for: (1) creating general environmental brightnesses agreeable and beneficial to the user, and (2) permitting a high degree of efficiency in seeing the necessary tasks with a minimum of effort."[1]

In satisfying this definition we have come to find that the essential consideration is the brightness of the task and the relation of that brightness to other areas of brightness in the field of view. Since in many cases the field of view keeps changing it becomes a matter of the relation of brightnesses in the whole environment.

Our illuminating engineers are constantly being confronted by new problems -- visual tasks strange to their previous experience and with different environments. That is what makes their life interesting because of the constantly changing situations with new challenges to ingenuity in applying the principles of illumination. The tasks are generally not entirely strange since there are elements of similarity that follow through many of them but the combinations are ever producing a sense of unaccustomed newness. It then becomes a case of the engineer making an analysis of the essential elements and applying the known relationships of:

(1) the brightness of the task
(2) the brightness of the surroundings of the task
(3) the brightnesses in the environment in which the field of vision moves,

for optimum and comfortable seeing.

It should be noted in passing that quantity of illumination in footcandles is used by the engineer solely as a means to the end of providing brightness on all the surfaces concerned. In setting up his footcandle tables and listing the illumination required for various locations and tasks he is visualizing the average reflection factors encountered and therefore the fact that the end product for seeing is brightness. Unfortunately, up to the present time, footcandle or illumination meters are the most readily available and inexpensive light measuring instruments.

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Brightness of the Task

The main characteristics* of a task are commonly described by the engineers in terms of its size, the contrast of the distinguishing detail with its background and the time within which it is exposed to the observer or within which it can just be recognized.

Size

The work of Lythgoe[2] (Fig. 1) represents a good average of those who in recent times have studied carefully the increase in the ability to see smaller size (Landolt's "C" - black on white) with the increase of brightness on the test object.

Contrast

A composite curve[3] (Fig. 2) derived from a correlation of four investigations represents the increase in the ability to see smaller contrast with the increase of brightness on the task.

Time

A family of curves[3] (Fig. 3) show the decrease in the time of identifying several sizes of the task with the increase of brightness (i.e., increase of illumination on the task consisting of the Landolt "C" whose background and detail had reflection factors of 78 per cent and 3 per cent respectively).

Visual Performance

The ability to perform in minimum time visual tasks varying in size and in contrast with the increase of brightness has been determined carefully at the National Physical Laboratory (London) by Weston[3,4]. A nomogram, Fig. 4, shows the illumination required for a task having a given size and difference of reflection factor* to permit 98 per cent of maximum visual performance.

It is seen that a deficiency in one or the other of the factors of size or contrast can be partially compensated by an increase in brightness (given in terms of illumination in above nomogram). The same percentage performance in a task having less contrast or smaller size can be attained by the increase in illumination over that on a task having a corresponding better contrast or larger size.

Visibility Meter

Another approach to the problem of recommending the brightness of the

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*Other characteristics are its specularity its transparency, its texture, its three dimensional appearance and its color. Each of these the engineer has studied in an effort to produce a practical illumination effect for suitable portrayal. Some studies are available on the treatment of each. According to current knowledge, colors (especially those which are unsaturated) have little effect on visibility but should be considered for their psychological and aesthetic effect.

*The British work[4] established the relationship that the illumination required for other than 100 per cent contrast is obtained by multiplying that required for 100 percent contrast by:

$$\frac{\text{one}}{\text{difference in reflection factors of background and detail}}$$

task is that presented by the Luckiesh-Moss Visibility Meter[5] which represents a mechanical integrator of the factors of size and contrast and is used to give an empirical index of the relative difficulty of tasks in proportion to a standard task of a parallel bar test object 1 minute in size under a brightness of 8 footlamberts (a calibration considered by the authors as representing a conservative base). It aids the lighting practitioner to evaluate quickly an unknown task and make recommendations of the illumination (e.g., brightness) according to the difficulty of the task.

Brightness of Surroundings of Task

Lythgoe[2] studied the effect on visual acuity of the brightness of the surroundings of his test object. Figure 5 shows the effect of dark, dimly-lighted and well-lighted surrounds. The solid line of the upper curve represents brightness equality of the surrounds and the task. The dotted portion illustrates surrounds maintained at 38.1 footlamberts. Equality of the brightness of the surrounds and that of the task appears preferable.

Cobb[6] studied the effect of the surrounds on the ability to see minimum perceptible contrast. Figure 6 illustrates the desirability of equality of brightness of the surrounds and that of the task.

Cobb[7] studied the effect of the brightness of the surrounds on the precision of performing a mechanical task guided by vision. The "fixed" pointer moved mechanically according to predetermined horizontal patterns unknown and seemingly erratic to the observer. The observer,by means of a handwheel, controlled and attempted to keep the alignment of the bottom pointer. The error was automatically recorded. Figure 7 illustrates the continued decrease in error with increase in brightness when the surrounds were equal to that of the task. However, dark surroundings entailed a loss of precision at all levels of illumination and an increasing error after about 30 footlamberts.

Further, Cobb investigated the effect of the size of the light surroundings upon the precision of performing the task. From Fig. 8 it appears that the maximum gain is reached when the field subtends an angle of about 30 degrees in radius.

Surroundings Brighter than Task

From Cobb's work as shown in Fig. 6 and from Lythgoe's work on surrounds, it is found that a decrease of ability to see minimum perceptible contrast and minimum size occurs rather rapidly when the brightness of the surrounds exceeds that of the task. A means of evaluating this effect has been developed by Moon[8,9] from the work of Holladay and Stiles.

In Fig. 9 let area of brightness B_1 represent the task and area of brightness B_3 be the surroundings, whose outer limit occupies a circular area of 1 radian in radius. The brightness B_A to which the eyes are adapted is some intermediate value between B_1 and B_3. Figure 10 permits the determination of B_A with varying relationships of B_1 to B_3 and size of B_1 to size of B_3.

When the brightness B_A to which the eyes are adapted is greater than B_1 (the brightness of the task), then the ability to see or the visibility of

the object is decreased according to Fig. 11.

Brightnesses in the Environment

The preformance of duties or the relaxation from them may bring about a movement of the visual field from one area to another. This causes different patterns of brightness to be encountered and depending upon their relationship to the previously fixated areas there will be a gain or loss of visibility. The above figures (9, 10 and 11) apply to this condition at least momentarily. If a predetermined movement is involved in the accomplishment of tasks, the relative visibility can be calculated for each condition.

In general the illuminating engineers have set up a rule of practice[10] that for good seeing conditions the brightness ratio of 3 to 1 or less should be used. This is especially applicable to the areas pertaining to the task itself. Higher values may cause fatigue or serious momentary loss of visibility in quick shift of observation. Where relaxation is involved or casual observation, higher ratios may be used without serious detriment except the momentary loss in looking from an area of higher brightness to that of lower value.

For instance, in office lighting the illuminating engineers are now recommending the following as representative of good practice:

Recommended Brightness Ratios[11]

Brightness ratios for areas of appreciable size from normal viewpoints should not exceed:

3 to 1	Between tasks and adjacent surroundings,
10 to 1	Between tasks and more remote surfaces,
20 to 1	Between luminaires (or windows) and surfaces adjacent to them,
40 to 1	Anywhere within the normal field of view.

These ratios are recommended as maximums; reductions are generally beneficial.

To accomplish this they are recommending the following reflectances[11] for good brightness ratios in the office environment:

Ceiling	85 per cent
Walls	60 " "
Desk Tops	35 " "
Furniture	35 " "
Floors	30 " "

While we have been unable to help Mr. Darr with his specific problems because of their complexity and the need for study of all of the elements, we have tried to set forth the principles and basic material from which he and his associates can make further detailed study.

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CAPTIONS

Fig. 1 - Visual acuity (or size in visual angle) vs. brightness.

Fig. 2 - Minimum perceptible contrast $\frac{(B_1 - B_2)\ min}{B_1} = C_{min}$ and contrast sensitivity $(1/C_{min})$ vs. brightness of background (B_1).

Fig. 3 - Speed of vision vs. illumination. Task -- identifying position of International Test-Object.

Fig 4 - Footcandles required for 98 per cent of maximum visual performance.

Fig. 5 - The influence of surrounding brightness on visual acuity.

Fig. 6 - The relationship between minimum perceptible brightness difference and the ratio of the brightness of the task to the brightness of the surrounding field.

Fig. 7 - The effect of surroundings and illumination upon the precision of performing a mechanical task guided by vision.

Fig. 8 - The influence of the extent of the bright task-field upon the precision of performing a mechanical task guided by vision. The mean deviation in per cent is plotted against the size of the bright field expressed in degrees visual angle which it subtends. The positive per cent values indicate deviations greater than the average; the negative per cent values indicate deviations less than the average. The angles represent the diameter of the bright field.

Fig. 9 - Condition when surroundings have brightness different from that of the task. θ varies from $.75^{\circ}$ to 57.3°. B_1 = brightness of task area. B_3 = brightness of area surrounding the task. B_A = brightness to which eyes are adapted when $B_3 / B_1 = k$.

Fig.10 - Ratio of adaptation brightness (B_A) to task brightness (B_1) when the brightness (B_3) surrounding the task brightness is different from that of the task. Total field considered as 115° diameter composed of task background with B_1 brightness and the surrounding area with B_3 brightness. θ_1 = radius of task background. Values of k on the curves denote the relation of the surrounding brightness to that of the task.

Fig.11 - Loss of visibility when adaptation brightness B_A exceeds task brightness B_1.

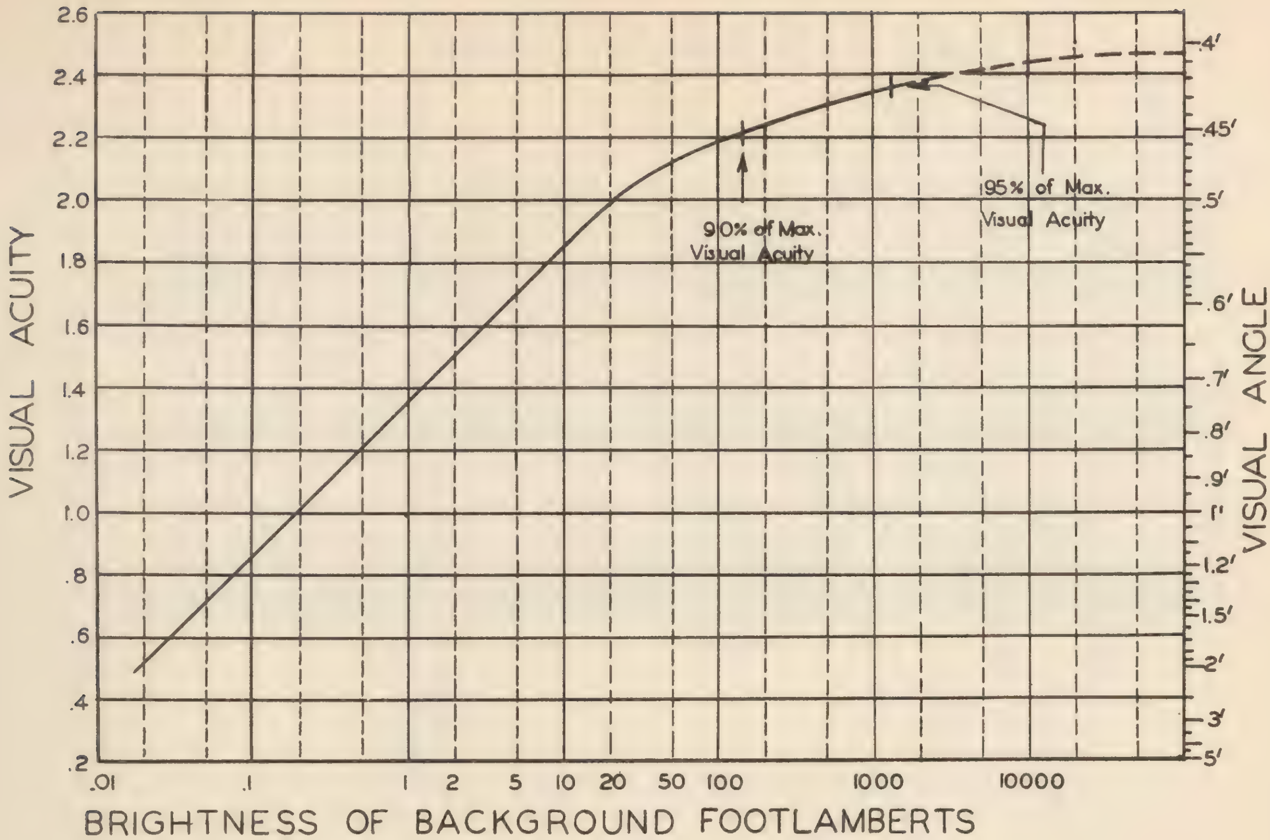


Figure 1

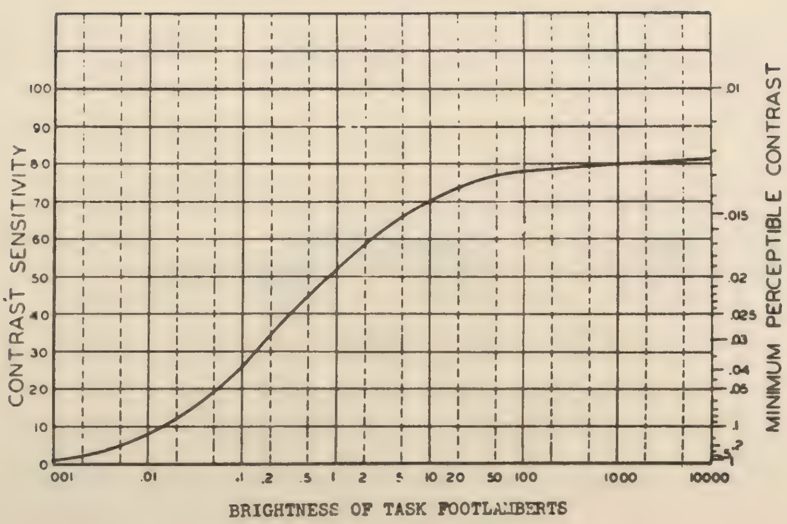


Figure 2

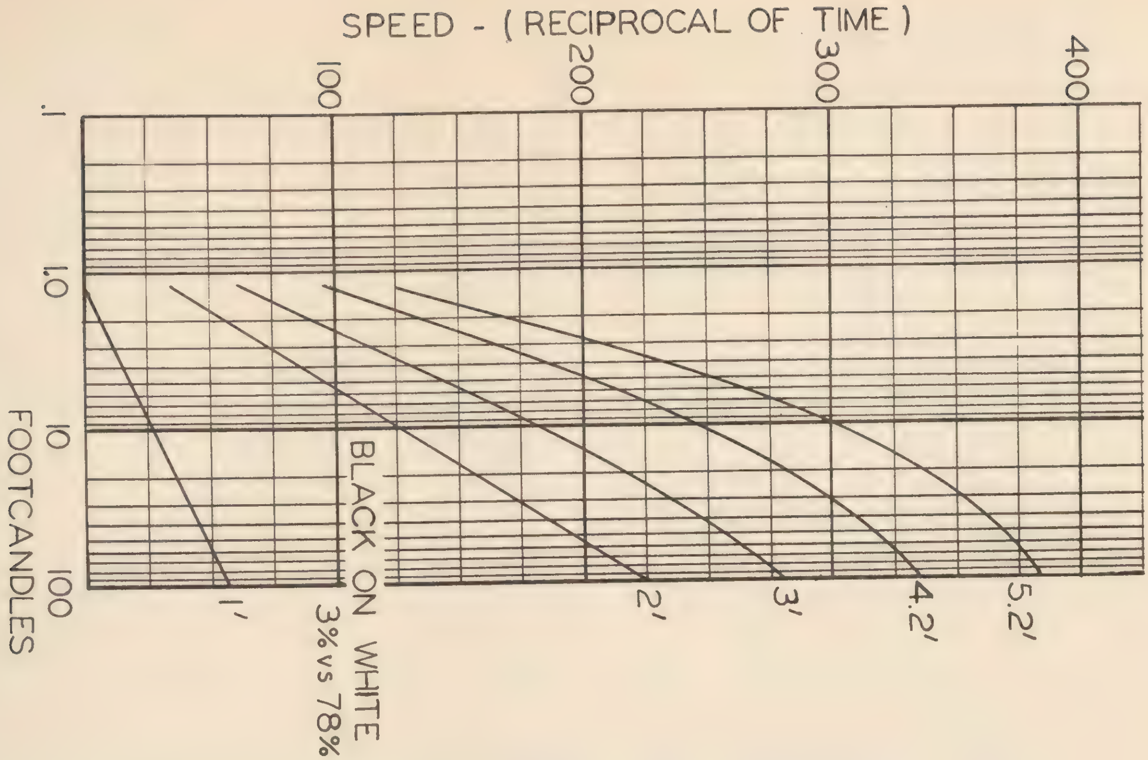


Figure 3

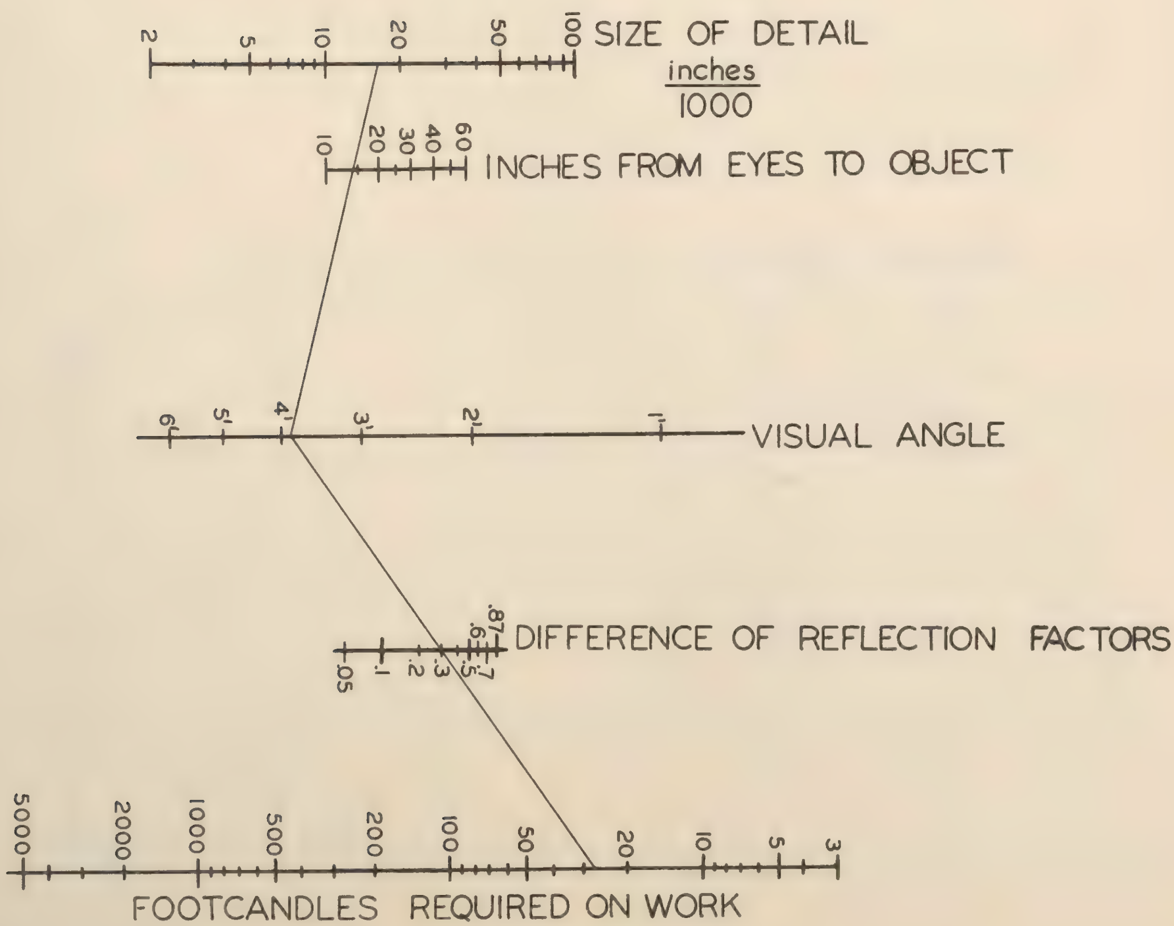


Figure 4

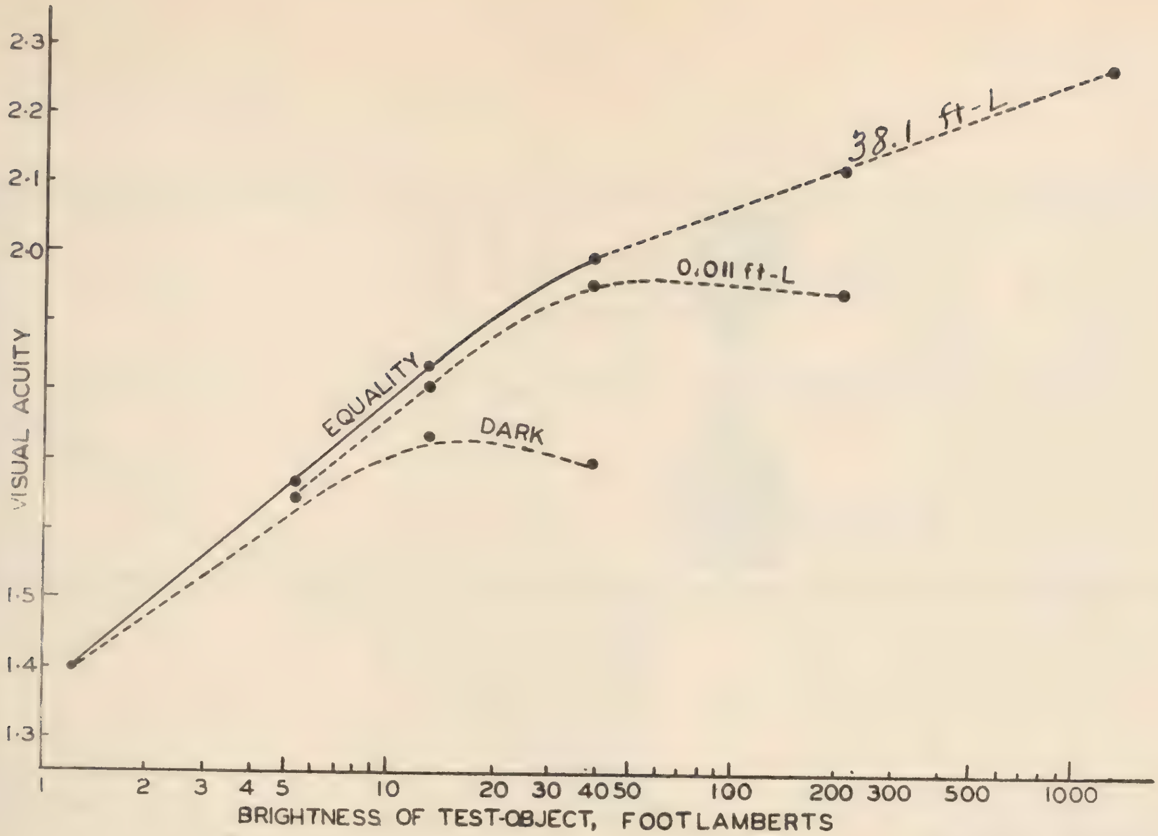


Figure 5

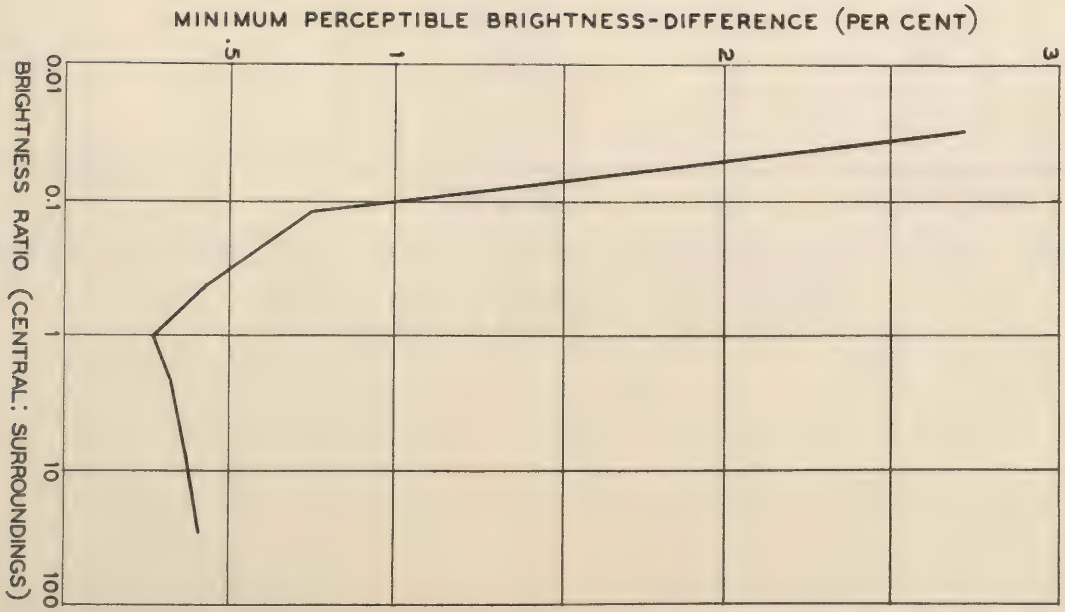
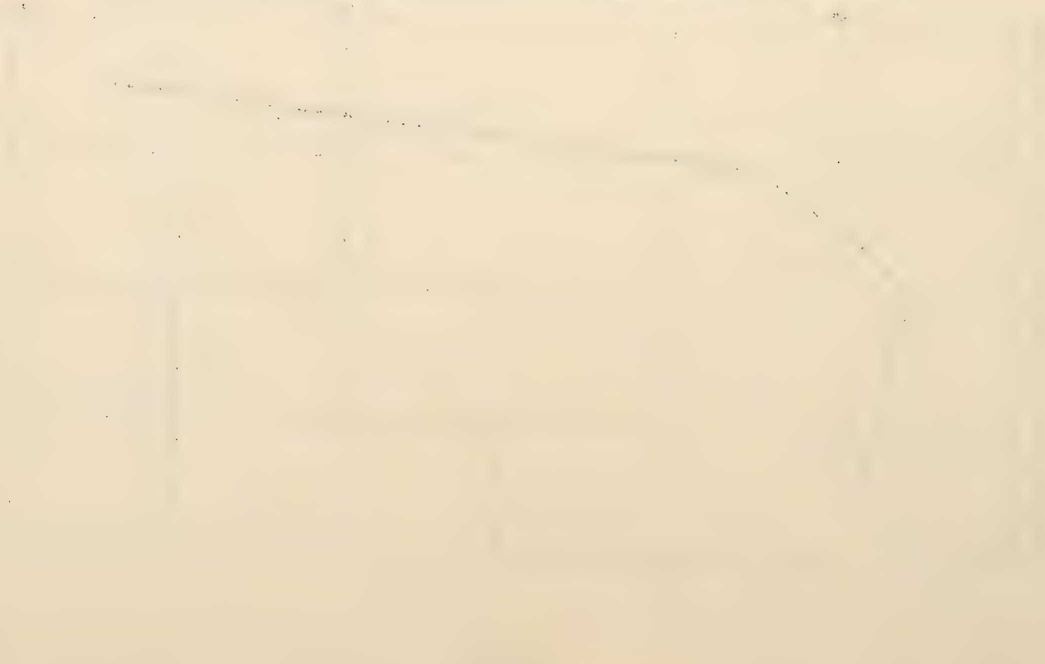


Figure 6

[illegible]

[illegible]

[illegible]



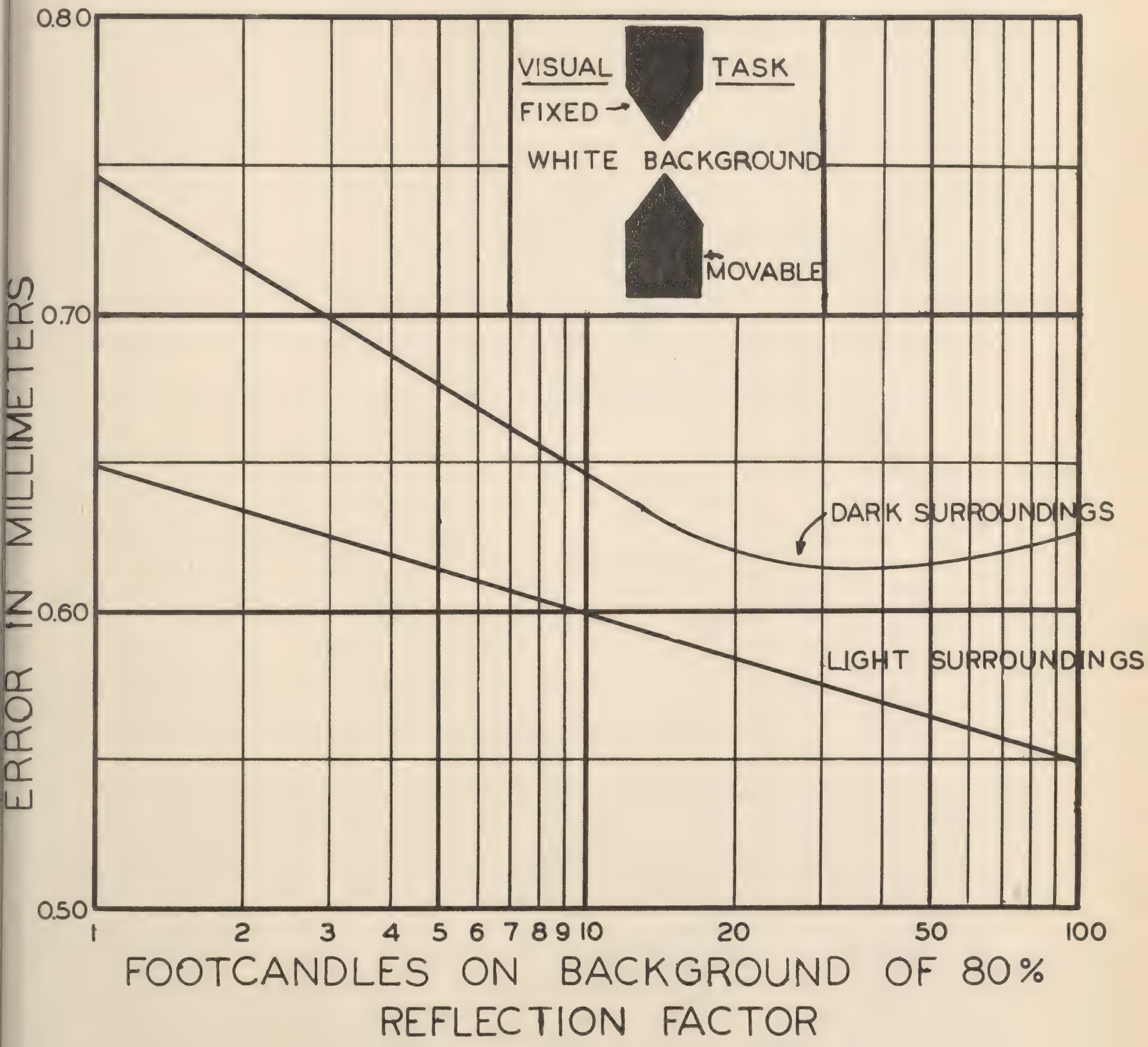

VISUAL TASK
FIXED
WHITE BACKGROUND
MOVABLE
DARK SURROUNDINGS
LIGHT SURROUNDINGS
ERROR IN MILLIMETERS
0.80
0.70
0.60
0.50
1
2
3
4
5
6
7
8
9
10
20
50
100
FOOTCANDLES ON BACKGROUND OF 80%
REFLECTION FACTOR

Figure [illegible]

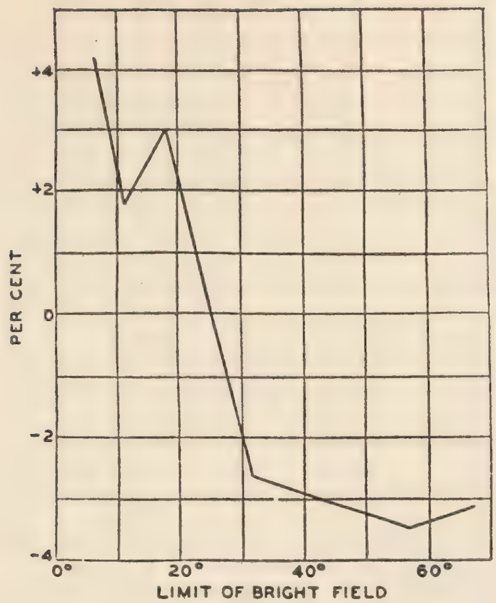


Figure 8

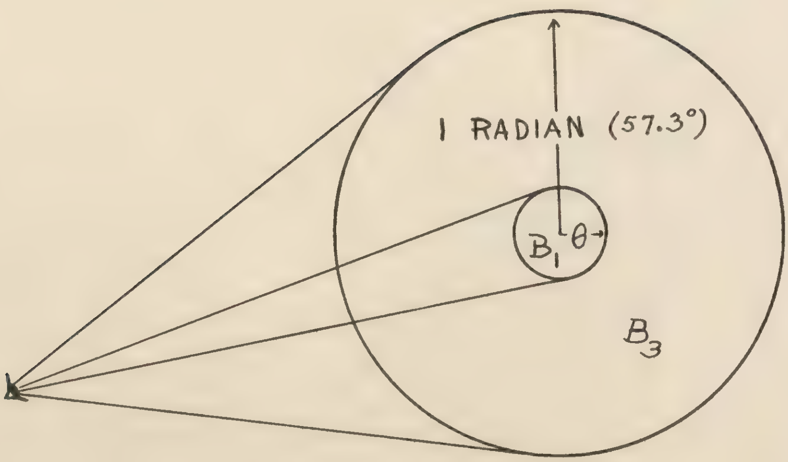


Figure 9

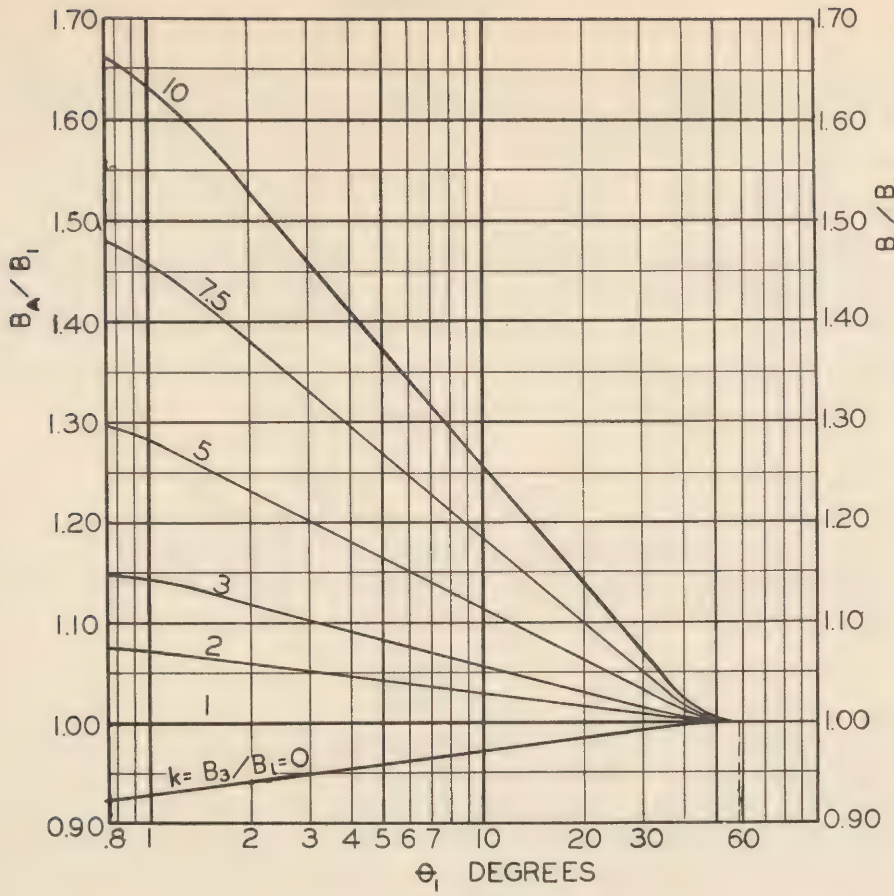


Figure 10

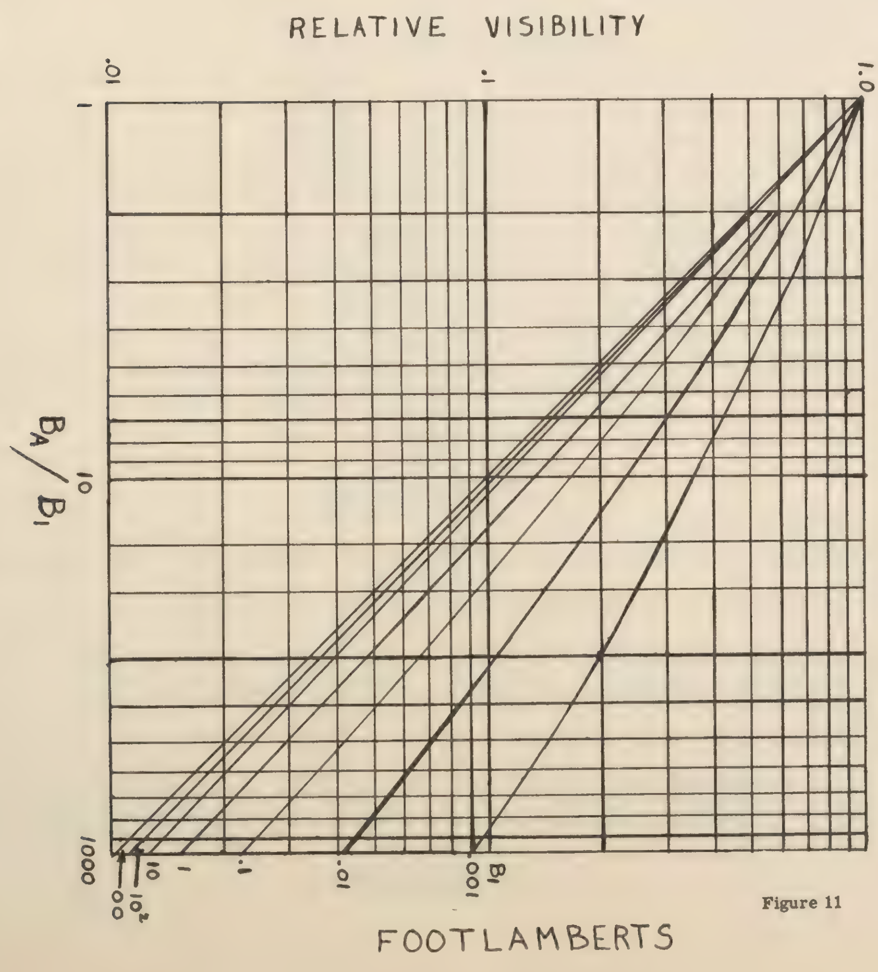


Figure 11

STRAY LIGHT CAUSED BY THE PRESENCE OF A LUMINOUS BODY WITHIN THE FIELD OF AN OPTICAL SYSTEM*

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*The work presented in this paper was performed, in part, as Task C of Navy Contract NOrd 7958 between the Bureau of Ordnance of the Navy Department and The Pennsylvania State College.

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by

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ABSTRACT

The stray light caused by a luminous body within the field of an optical system has been measured for a variety of conditions. Contrast Rendition measurements were made for three pairs of telescopic systems and two pairs of photographic systems, each pair consisting of one coated and one noncoated specimen. The measurements were made for various angular distances between a black target in a uniformly illuminated surround and a luminous body of which the brightness could be varied with respect to the background. The Contrast Rendition measurements were made for conditions in which the brightness of the luminous body ranged from ten to ten thousands times the brightness of the target. Each pair of optical systems was studied under two conditions of alignment with respect to the target. The first was such that no strong ghost image of the luminous body was likely to fall upon the image formed of the target. The second case was such that the strongest ghost image of the luminous body fell upon the image of the target when the angular separation between the target and the luminous body was 2°. The Contrast Rendition values were found to range from approximately 90 to 1 percent for the various cases studied. In general there somewhat was less stray light found in the specimens coated with reflection-reducing films than in the noncoated systems. The general trend of the data, however, was found to be the same for all the specimens studied in that Contrast Rendition started to drop rapidly when angles between the target and the artificial sun became less than a few degrees.

INTRODUCTION

In a recent paper[1], a general method was described for measuring the stray

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Reference 1: H. S. Coleman, "Stray Light in Optical Systems," to be published in June issue of J.O.S.A., 1947.

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light in optical systems. In this paper consideration is given to the special case of stray light produced by a luminous body either within or near the edge

of the field of an optical system under consideration. There are many well known examples which might be cited in which observations or photographs must be taken in which the stray light caused by high lights produce a considerable loss in detail. This loss in detail has been described in terms of the loss in brightness contrast of the image caused by the stray light. It has been found convenient to introduce a property of an optical system referred to as the "Contrast Rendition." The Contrast Rendition is a percentage comparison of the contrast of the image form of an object with the contrast the object as measured at the entrance window of the optical system under consideration. The Contrast Rendition, C.R., may be expressed in terms of the image contrast, C_i, and the apparent contrast of the object, C_a, as shown in equation (1).

$$(1) \quad C.R. = \frac{C_i}{C_a} \times 100$$

The Contrast Rendition of an optical system has been shown to be a function of brightness characteristics of the region surrounding the object under consideration. The subtense of natural objects may vary over a wide range. For the purposes of this paper the subtense is selected such that it may be considered an extended object from the point of view of diffraction theory but small ($1/4^{\circ}$) with respect to the surround (180°). It is believed that objects of this subtense are of common interest in visual and photographic detection problems.

Because of the numerous ramifications into even the obvious applications of information concerning the magnitude of the stray light produced by luminous bodies with the field of an optical system, the scope of this paper has been limited as much as possible to the methods used and the numerical results obtained. Special consideration is given to the influence of reflection-reducing films on the Contrast Rendition of common optical systems.

APPARATUS AND PROCEDURE

The apparatus and procedure for making stray light measurements is essentially the same as reported previously. The only difference in the apparatus is the addition of a luminous body, referred to as "the artificial sun," which can be moved about in the field with respect to the target under observation. This is shown schematically in figure 1. The artificial sun is arranged such

Figure 1: Schematic Diagram of Contrast Rendition Apparatus and Artificial Sun.

that its presence or absence does not appreciably change the brightness of the background against which the target was viewed. The subtense of the artificial sun and the target are $1/4^{\circ}$ as measured from the entrance pupil of the optical system under test.

The procedure consisted of making Contrast Rendition measurements of the target (a black hole in a 180° uniformly illuminated surround) for various angular separations between the artificial sun and the target. To cover most practical cases, four different brightness ratios were studied of the artificial sun with respect to the background against which the target was viewed. These were such that the brightness of the artificial sun was 10, 100, 1,000, and

10,000 times the brightness of the background. Two extreme conditions of alignment of the target and optical system under test were used. The first was such that a ghost image of the artificial sun was likely to fall upon the image of the target formed by the optical system under test for some angular position with respect to the target as the artificial sun was moved across the field. For purposes of comparison, this condition was selected such that the strongest visible ghost image would fall on the image of the target when the artificial sun was separated from the target by 2°. The second condition of alignment was such that in general no strong ghost image of the artificial sun was likely to fall on the image of the target formed by the optical system under test. In this latter case, the optical system under test was adjusted such that the image of the target would fall on the optical axis.

The optical systems discussed in this paper consist of three pairs of telescopic systems and two pairs of photographic objectives. Each pair consisted of one specimen having its optical surfaces coated with reflection-reducing films and the other specimen of the same design but with noncoated surfaces. The telescopic systems consisted of an 8x40x5.2° periscope, a 7x50x7.1° prism erecting binocular, and a 5x35x12.5° lens erecting gunsight. The photographic objectives were Ic Tessar and the Altimar designs.

THE DATA

The data are presented graphically in figures 2 to 17 inclusive.

Figure 2: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Noncoated 8x40x5.2° Periscopic System.

Figure 3: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Coated 8x40x5.2° Periscopic System.

Figure 4: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Noncoated 8x40x5.2° Periscopic System.

Figure 5: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Coated 8x40x5.2° Periscopic System.

Figure 6: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Noncoated 7x50x7.1° Prism Erecting Telescopic System.

Figure 7: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Coated $7x50x7.1^{\circ}$ Prism Erecting Telescopic System.

Figure 8: Contrast Rendition For Various Angular Distances Between the Artificial Sun and the Target for a Non-coated $7x50x7.1^{\circ}$ Prism Erecting Telescopic System Rotated 1° Off Axis to the Left.

Figure 9: Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for Coated $7x50x7.1^{\circ}$ Prism Erecting Telescopic System Rotated 1° Off Axis to the Left.

Figure 10: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Non-coated $5x35x12.5^{\circ}$ Lens Erecting Telescopic System.

Figure 11: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Coated $5x35x12.5^{\circ}$ Lens Erecting Telescopic System.

Figure 12: Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Non-coated $5x35x12.5^{\circ}$ Lens Erecting Telescopic System Rotated 1° Off Axis to the Left.

Figure 13: Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for a Coated $5x35x12.5^{\circ}$ Lens Erecting Telescopic System Rotated 1° Off Axis to the Left.

Figure 14: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for Non-coated and Coated Altimar Photographic Objectives at f/5.

[redacted]

Figure 15: Axial Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for Non-coated and Coated Altimar Photographic Objectives at f/11.

Figure 16: Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for Non-coated Coated Altimar Photographic Objectives at f/5 Rotated 1° Off Axis to the Left.

Figure 17: Contrast Rendition for Various Angular Distances Between the Artificial Sun and the Target for Non-coated and Coated Altimar Photographic Objectives at f/11 Rotated 1° Off Axis to the Left.

Figures 2 and 3 show the data on the $8x40x5.2^{\circ}$ periscopes with the head prisms used on axis. In this case no strong ghost image of the artificial sun fell upon the image of the target as the artificial sun is moved across the field.

Figures 4 and 5 show the data obtained for the $8x40x5.2^{\circ}$ periscopes with the head prisms set at approximately 2.0° depression. At this depression, the strongest ghost visible fell upon the image of the target when the artificial sun was separated from the target by 2°.

Figures 6 and 7 show the data obtained for the right barrels of the $7x50x7.1^{\circ}$ binoculars when the image of the target is on the axis of the optical systems. In this particular case strong ghost image of the artificial sun fell upon the image of the target.

Figures 8 and 9 show the data obtained for the right barrels of the $7x50x7.1^{\circ}$ binoculars rotated 1° off-axis to the left. For this rotation, a strong ghost image of the artificial sun fell upon the image of the target when the artificial sun was separated from the target by 2°.

Figures 10 and 11 show the data obtained for the $5x35x12.5^{\circ}$ gunsights aligned such that the image of the target fell on the optical system's axis. In this case no particularly strong ghost image of the artificial sun fell upon the image of the target as the artificial sun was moved across the field.

Figures 12 and 13 show the data obtained for the $5x35x12.5^{\circ}$ gunsights rotated at 1° off-axis to the left. For this rotation, a strong ghost image of the artificial sun fell upon the image of the target when the artificial sun was 2° from the target.

Figures 14 and 15 show the data obtained for the Altimar objectives aligned with the image of the target falling upon the optical axis. In this case no particularly stray ghost image of the artificial sun fell upon the image of the target.

[redacted]

Figures 16 and 17 show the data obtained for the Altimar objectives rotated such that the target was off-axis by 1°. For this rotation, a strong ghost image of the artificial sun fell upon the image of the target when the artificial sun was separated from the target by 2°.

DISCUSSION AND CONCLUSIONS

The preceding data indicate that the reduction in contrast caused by stray light from a luminous body within the field of an optical system is of considerable magnitude. The data themselves, however, are not easily analyzed with respect to the causes of stray light. Such an analysis can be made by a visual examination of the image planes and the internal part of an optical system. This examination may be accomplished by means of a loupe in the case of an afocal system and by means of a white screen in the case of a focal system. By means of such examinations, the causes of the irregularities in the preceding graphs can be seen (repeated measurements indicate that the irregularities in the graphs are real and are reproducible). The visual examinations reveal that the causes of the individual irregularities may vary widely. Because of this each optical system and set of conditions under which the optical system is being considered must be treated separately. There are, however, a number of general conclusions that can be drawn from this study. These are presented in the following paragraphs:

1. The method used to measure stray light in optical systems is quite versatile and sufficiently precise to study a wide variety of conditions which are of practical interest.

2. The method described to measure the stray light has a certain face validity, at least in the case of telescopic systems, in that there is a close correlation between the visual examinations of the causes of stray light and the Contrast Rendition data obtained by photo-electric means.

3. It is interesting to note that there is a great deal of similarity in the form of data obtained for the different designs of optical systems considered. It is to be noted that the true field subtense of an optical system has little relation with respect to angle between the target and the luminous body at which the Contrast Rendition curves start to fall rapidly. This appears to occur from 2° to 5° separation between the target and the luminous body regardless of the subtense of the field of the optical system under consideration.

4. The use of reflection-reducing films far from eliminates the stray light in the cases reported here. This indicates that a considerable portion of the stray light present is caused by reflection from the mechanical as well as the optical parts. It is evident, however, that reflection-reducing films do greatly reduce the stray light in the case of a ghost image falling upon the image of the target.

5. The causes of the irregularities in the graphical data presented here are found to be caused by diffuse and specular reflections from the optical and mechanical parts as well as from a considerable number of ghost images formed when the optical system is used off-axis even to a very slight degree. It might be noted that the irregularities caused by these reflections do not always occur symmetrically with respect to either the optical or mechanical axes.

This is a result of the nonuniformity in the internal surface treatment of the mechanical parts and of slight differences in the dimensions of the mechanical parts. As an example of the latter, the minimum occurring in the Contrast Rendition data at 4° to the left in figure 12 was caused by a diffuse reflection from the ground edge of one of the erecting prisms which had not been properly covered by the metal shield provided for that purpose. This same reflection was not found in the case of other noncoated systems of the same design.

6. The axial Contrast Rendition values are found to be fairly symmetrical and are generally higher than the off-axis measurements. This indicates that observations or photographs taken of objects near bright luminous regions should be such that the image of the object falls on the optical axis of the system being used.

7. In the case of the Altimar photographic objective, it is of interest to note that the Contrast Rendition is higher for the full aperture than at a reduced aperture. This indicates that the image-forming light is reduced more rapidly than the light from the ghost images as the aperture is reduced.

8. The most prevalent causes of ghost images in telescopic systems are the steep curves of the eyepieces and the flat surfaces of prisms, windows, and reticles. The results of experiments not described here, indicate that the use of reflection-reducing films are particularly effective in these cases.

9. The preceding data indicate that the use of ordinary lens shades would not be a practical means of reducing the stray light for natural conditions simulated in this study. The possibility is suggested, however, that an adjustable "lens shade" might be developed which would eliminate any desired portion of the field (such as near the image of a bright luminous object).

10. It is seen from the preceding data that there are two separate sources of stray light causing an imperfection in the Contrast Rendition of optical systems. The first of these is the uniform surround and the second is the luminous body. Since the stray light is rapidly diminished as the angle between the target and the luminous body is increased beyond a few degrees, Contrast Rendition remains constant for greater angles, regardless of the presence of the luminous body. This indicates how close observations or photographs could be taken to a bright luminous region with a given reduction in contrast.

11. The amount of stray light implied from the Contrast Rendition values reported here are conservative for two reasons. The first of these is inherent in the method used, in that by definition, the image contrast cannot be reduced below zero. This holds even in the case of a ghost image falling on the image of the target that is many times brighter than the image of the background. The second reason is that there is no account taken of the stray light introduced by the observer's eye or the photographic plate. Such stray light would further reduce the contrast for the conditions discussed in this experiment.

ACKNOWLEDGEMENT

The author is indebted to Dr. M. F. Coleman, Mr. S. W. Harding, and Mrs. A. E. Lerew, of the Optical Inspection Laboratory, for invaluable assistance in this study. The photographic objectives were made available through the courtesy of Dr. A. F. Turner of the Bausch and Lomb Optical Company.

Discussion:

Comdr. Dyke remarked that in the summer of 1941 a paper, including photographs, was made available on the effectiveness of reflection reducing films. The photographs included bright areas interspersed with dark areas. It was obvious that more detail in shadow could be seen on the photographs taken with coated lenses than with those taken with uncoated lenses. Commander Dyke asked whether a photographic method of evaluating the effect of coatings could be used.

Dr. Horsfall reported tests made to determine whether or not coatings were worth while. Several types of binoculars were prepared with and without coatings, and out-door vision tests were conducted. Recognition tests at extremely low levels of illumination did not reveal any difference between the two kinds of binoculars. However, for street scenes at twilight, with street lights on, vision through coated binoculars is superior to that through uncoated binoculars.

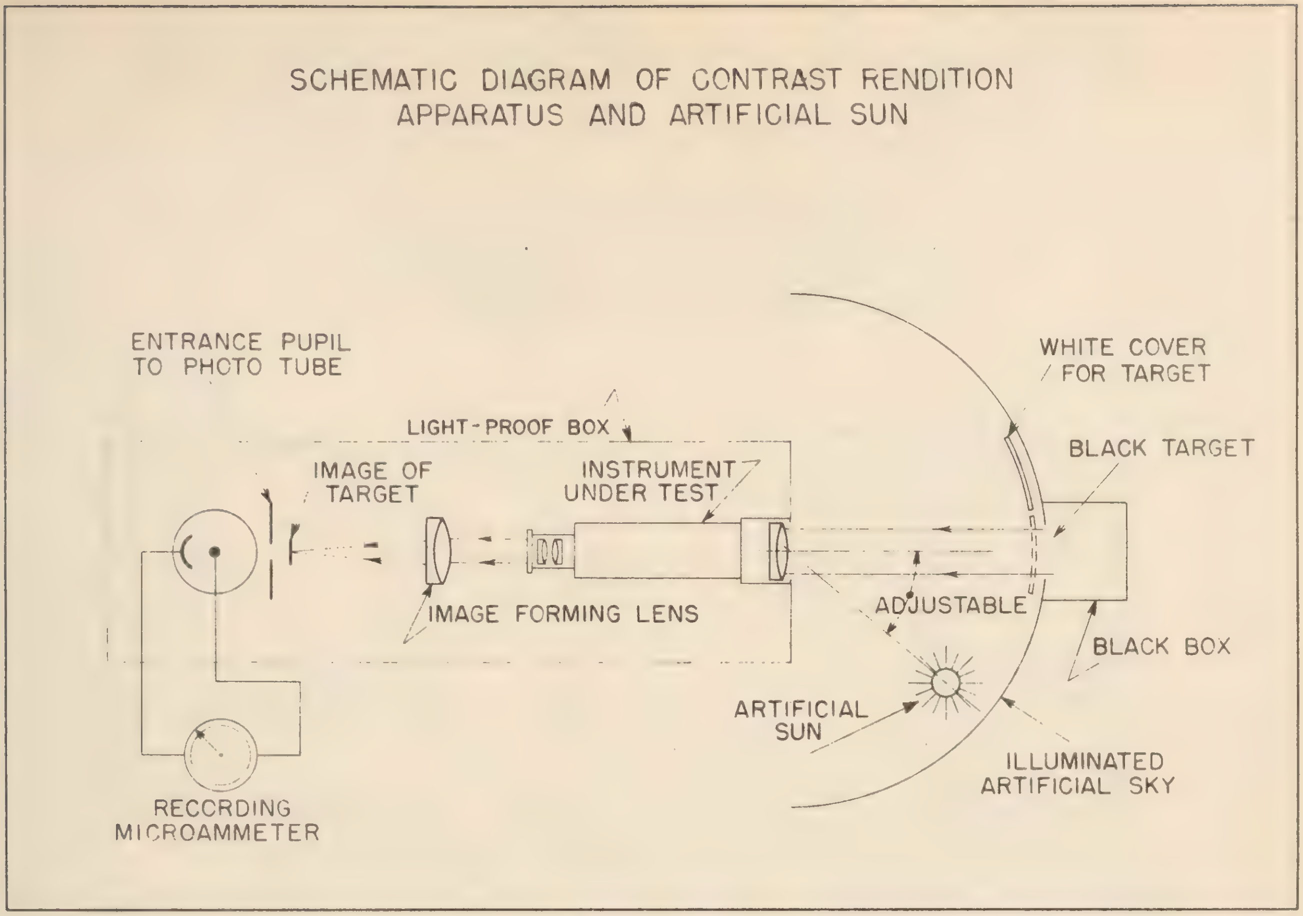


Figure 1

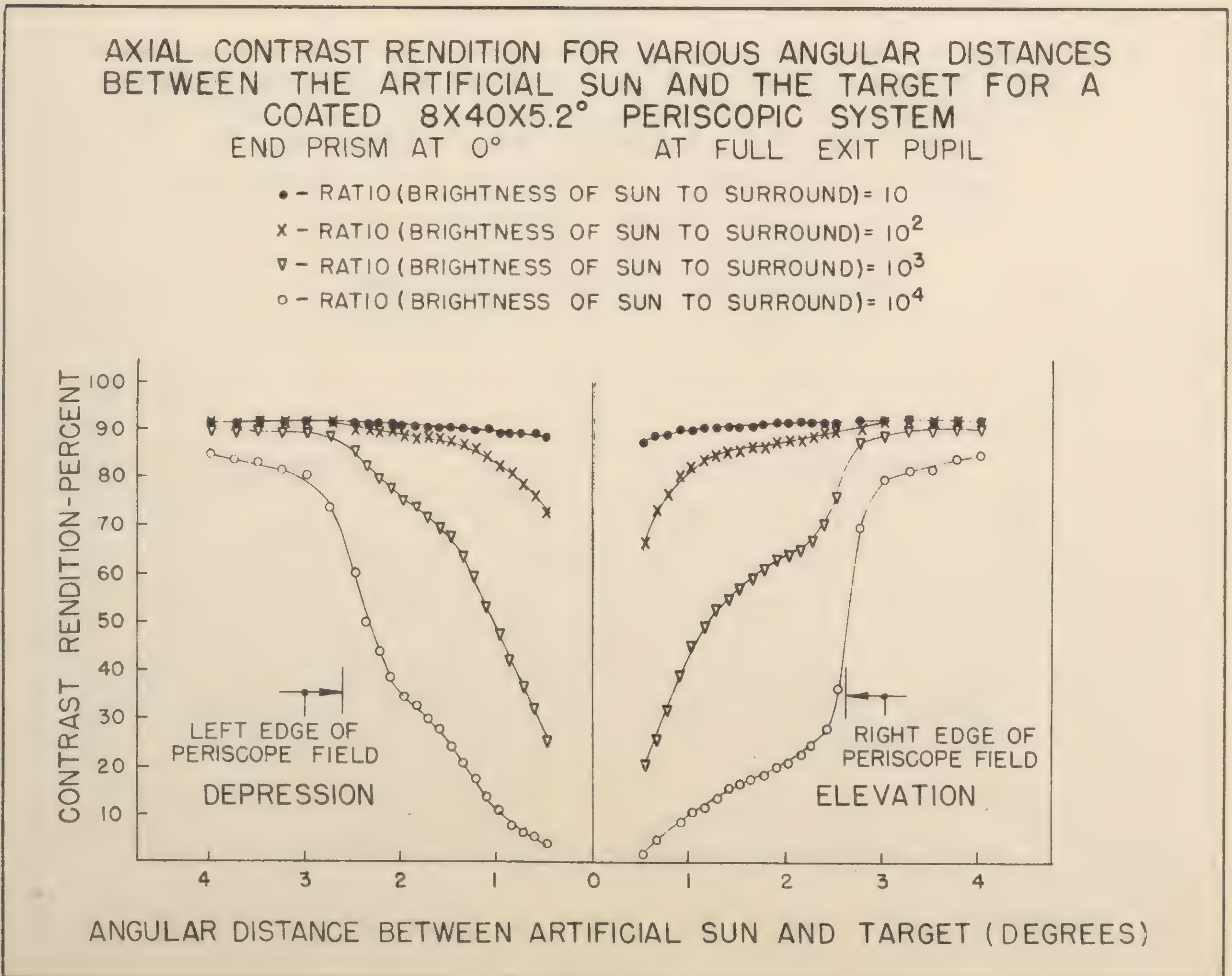


Figure 3

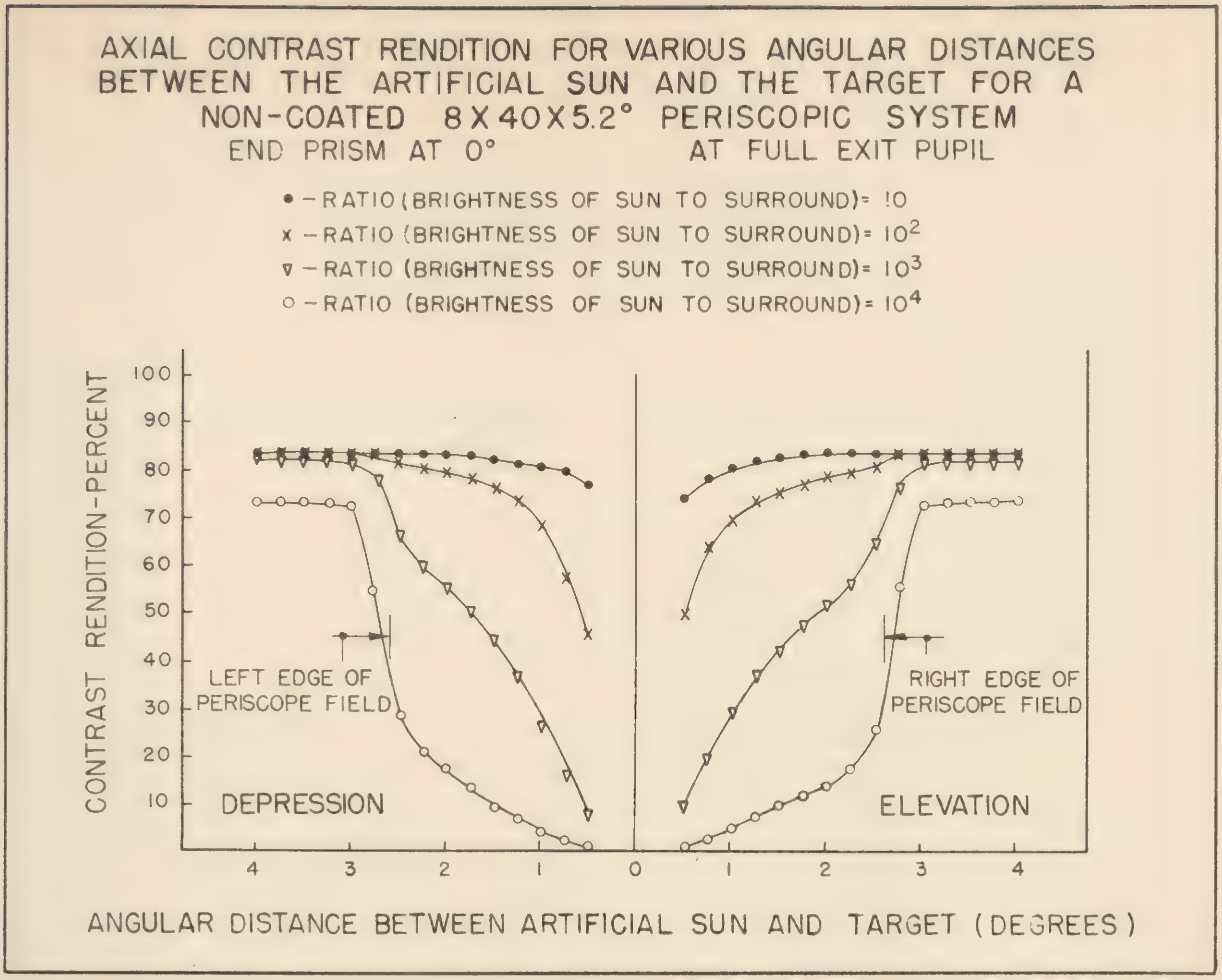


Figure 2

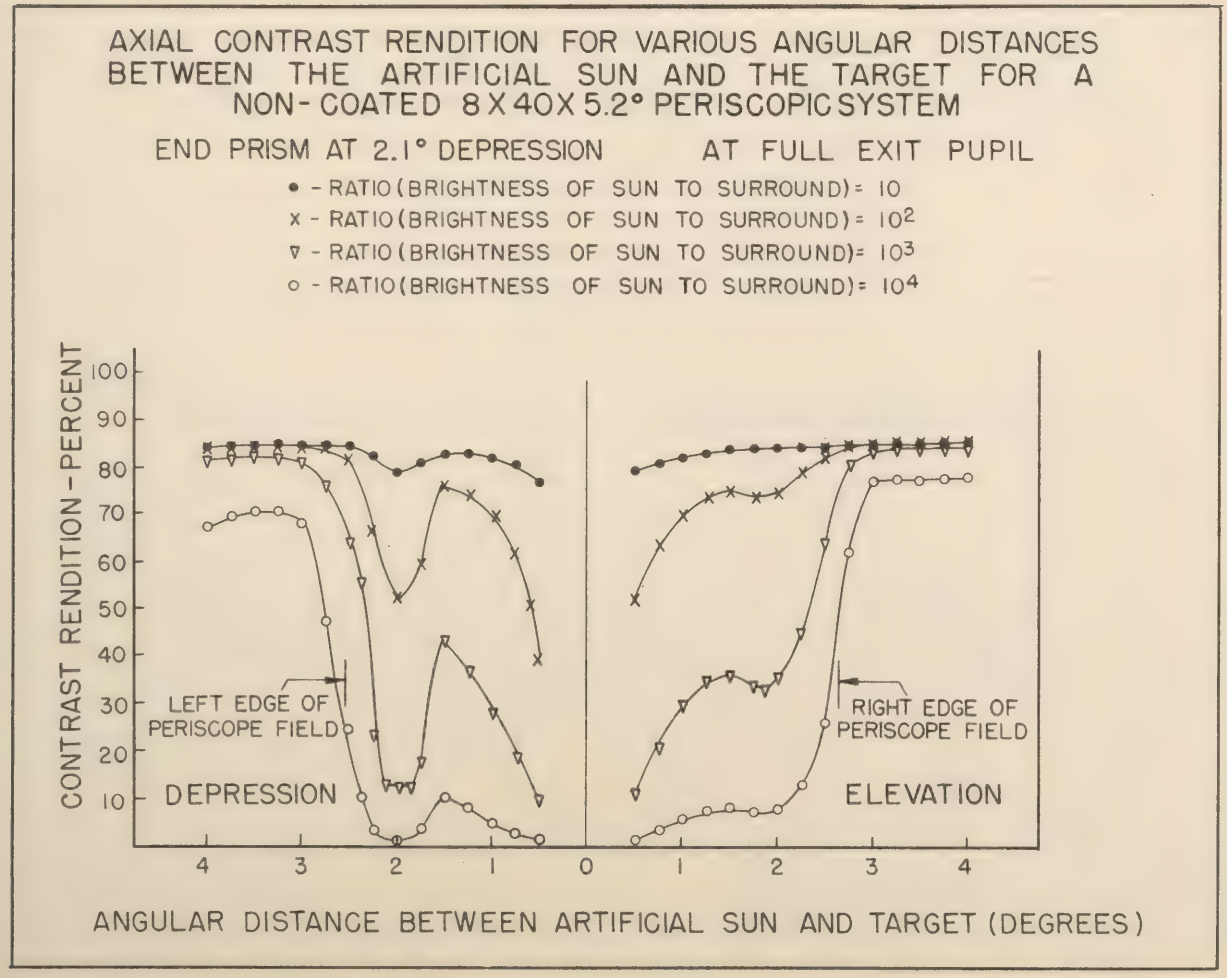
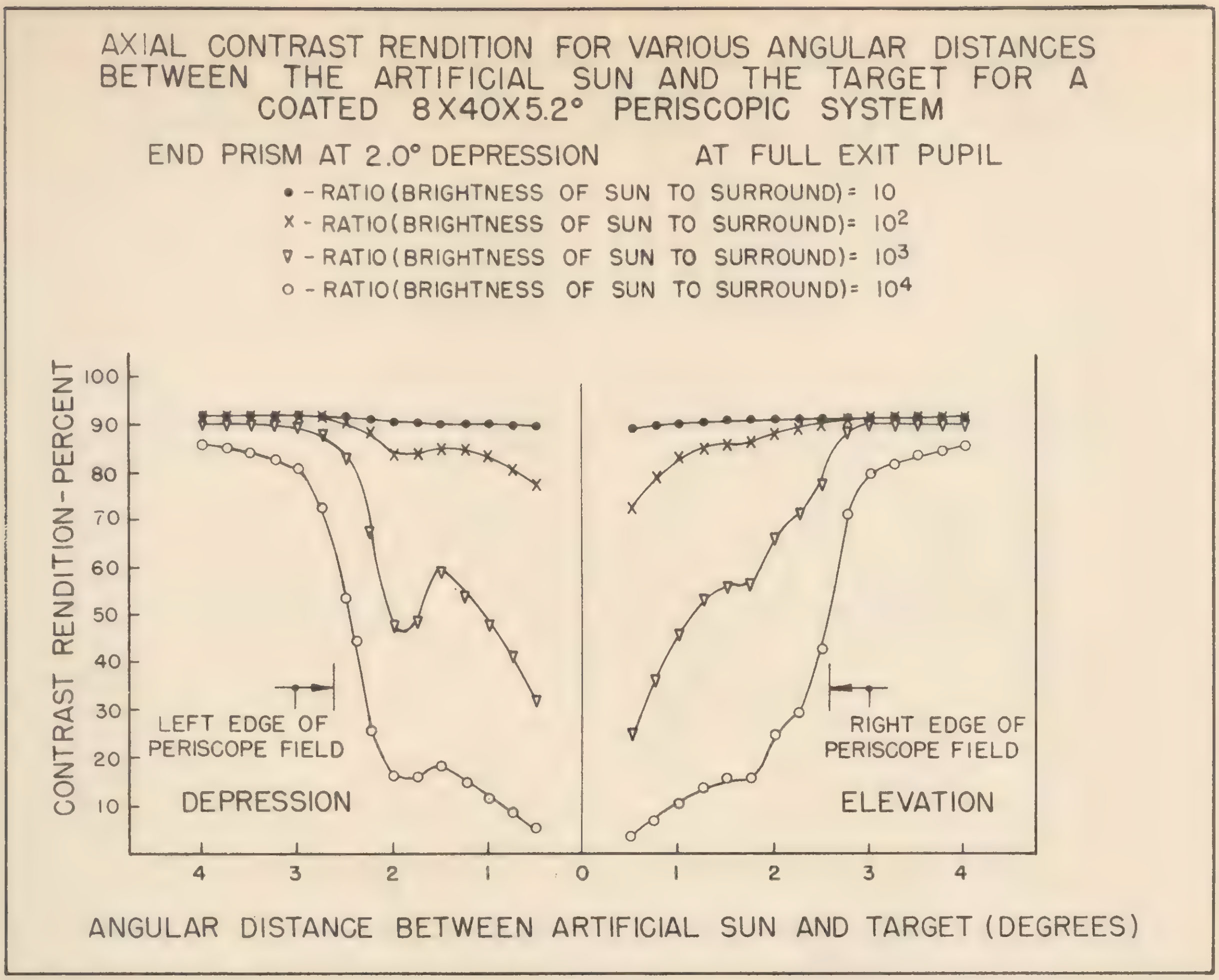


Figure 4



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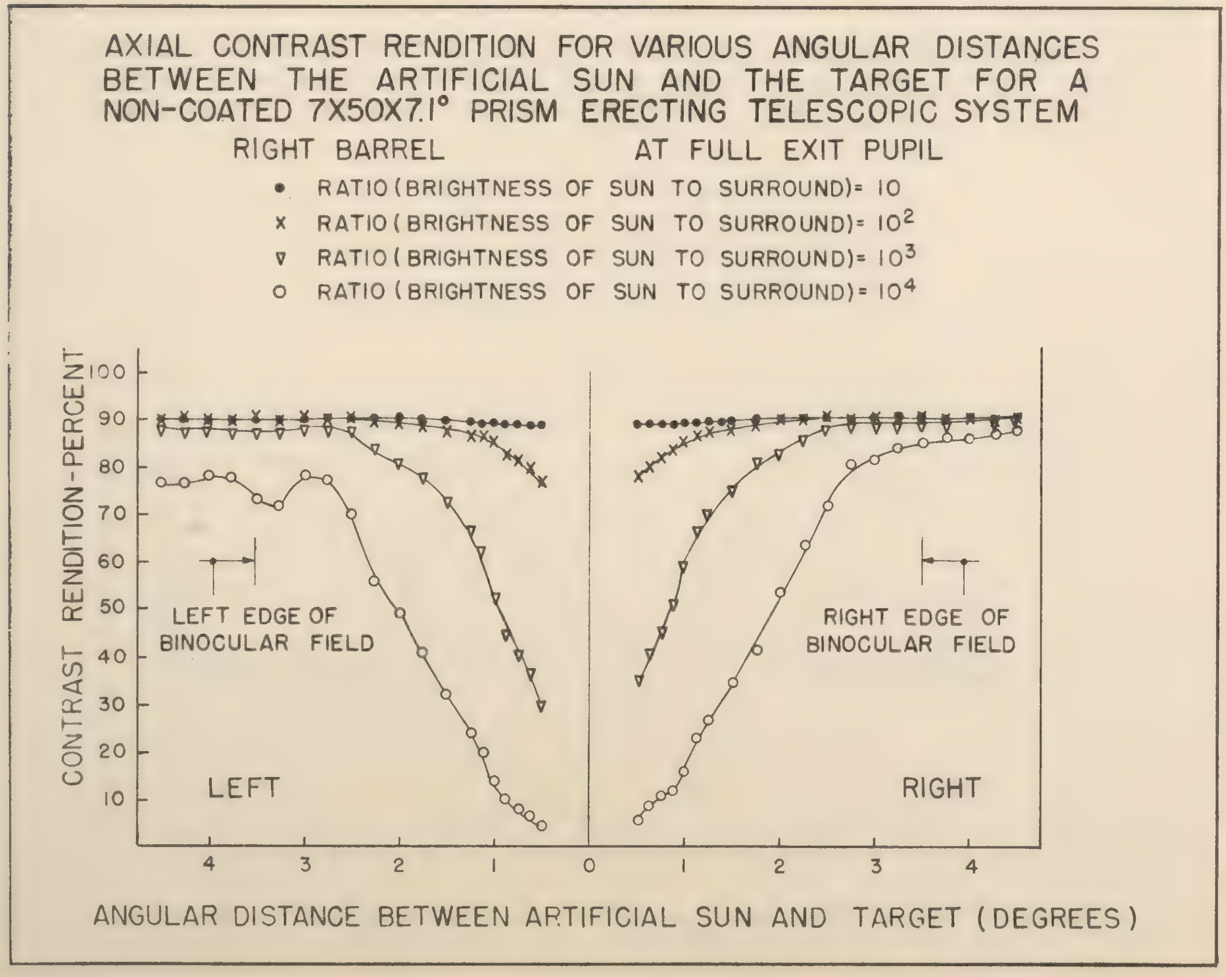

Figure 6

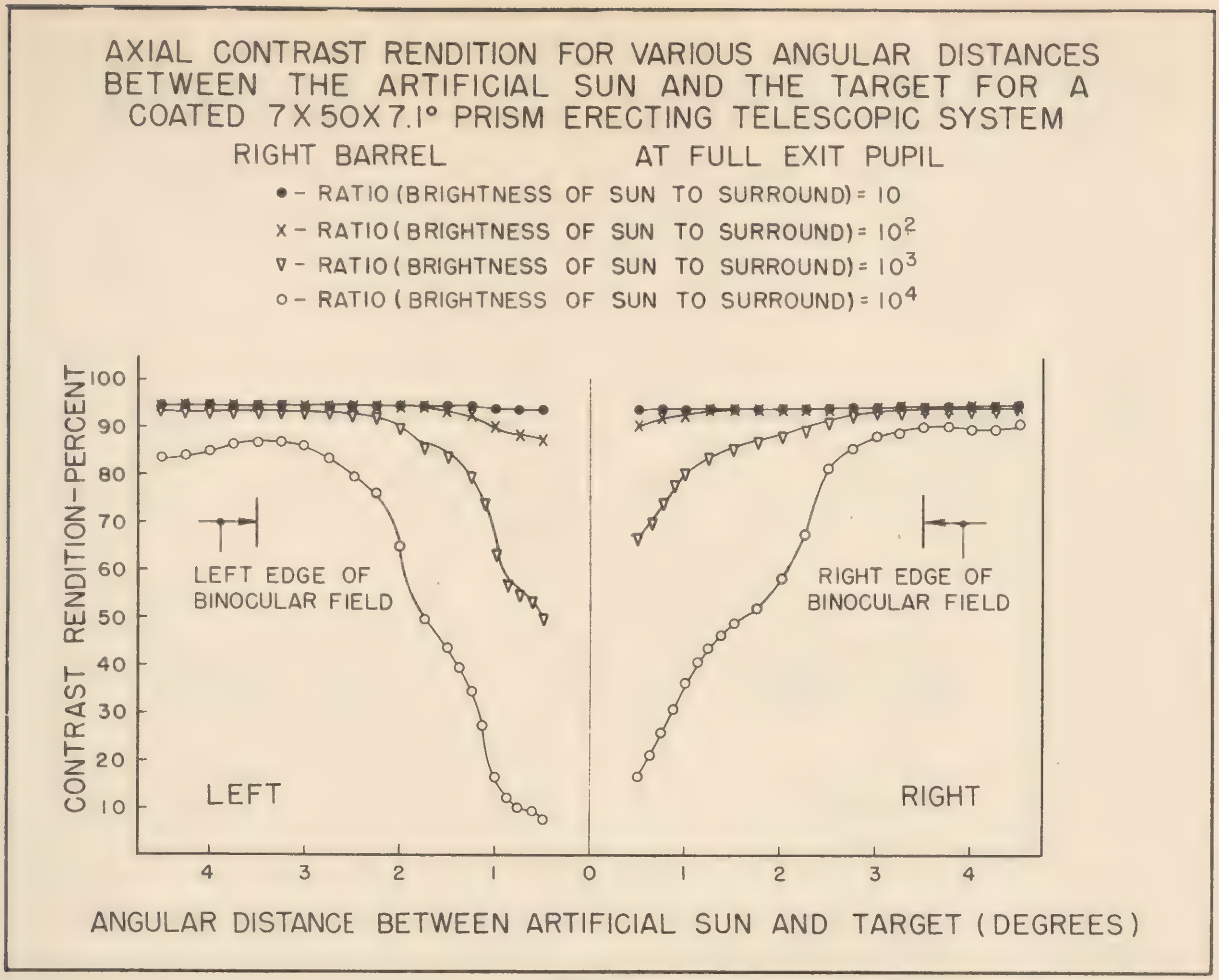

Figure 7

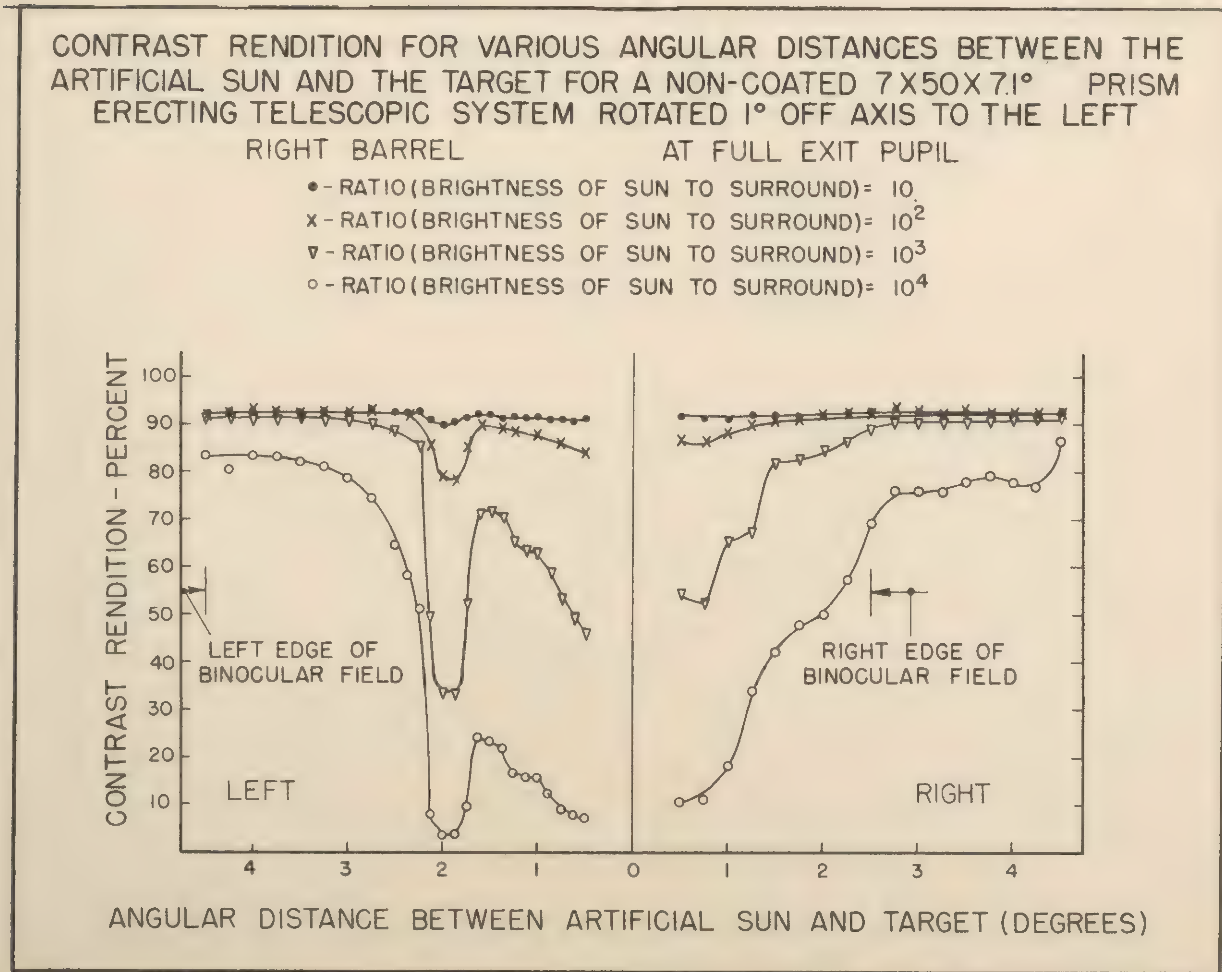

Figure 8

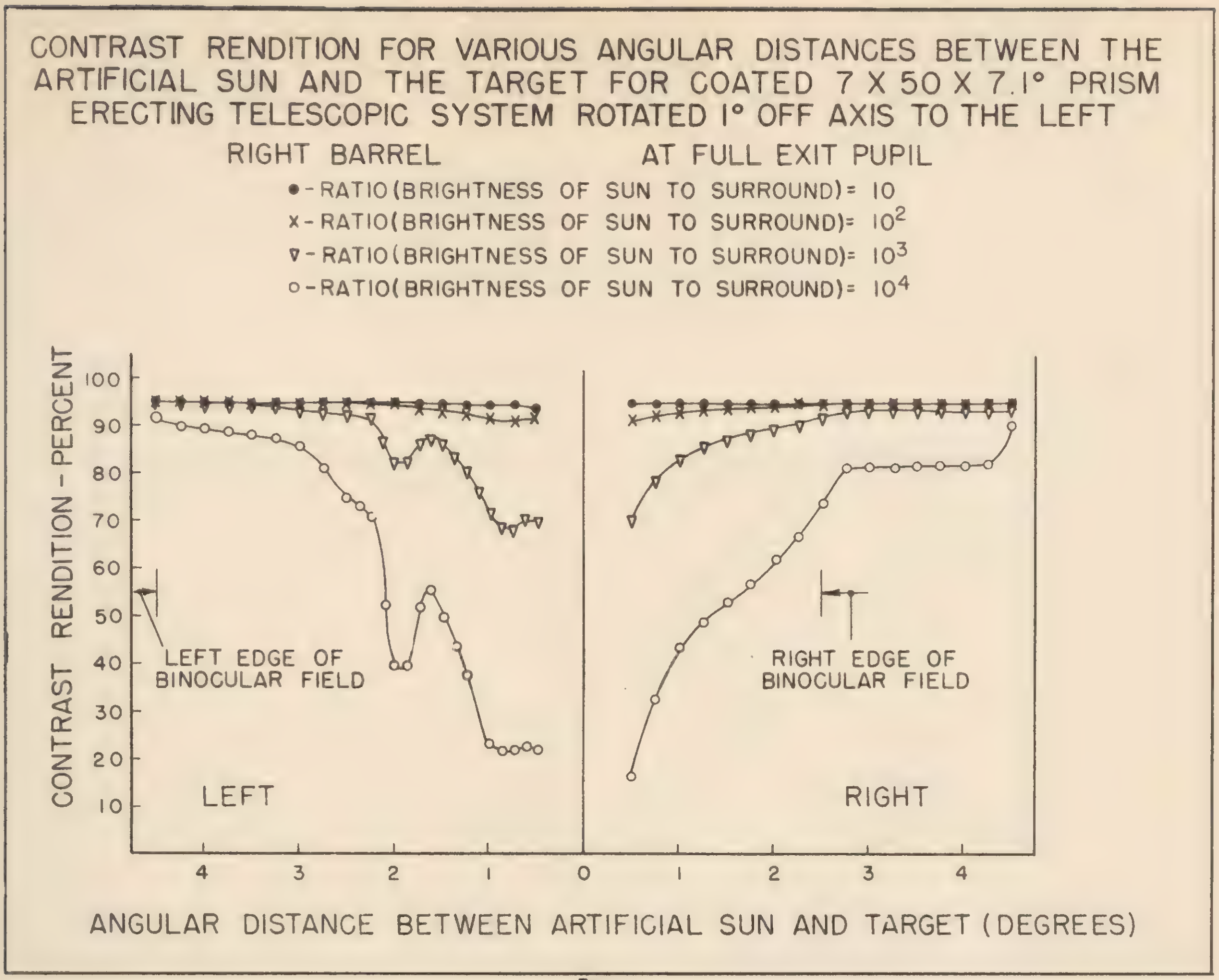

Figure 9

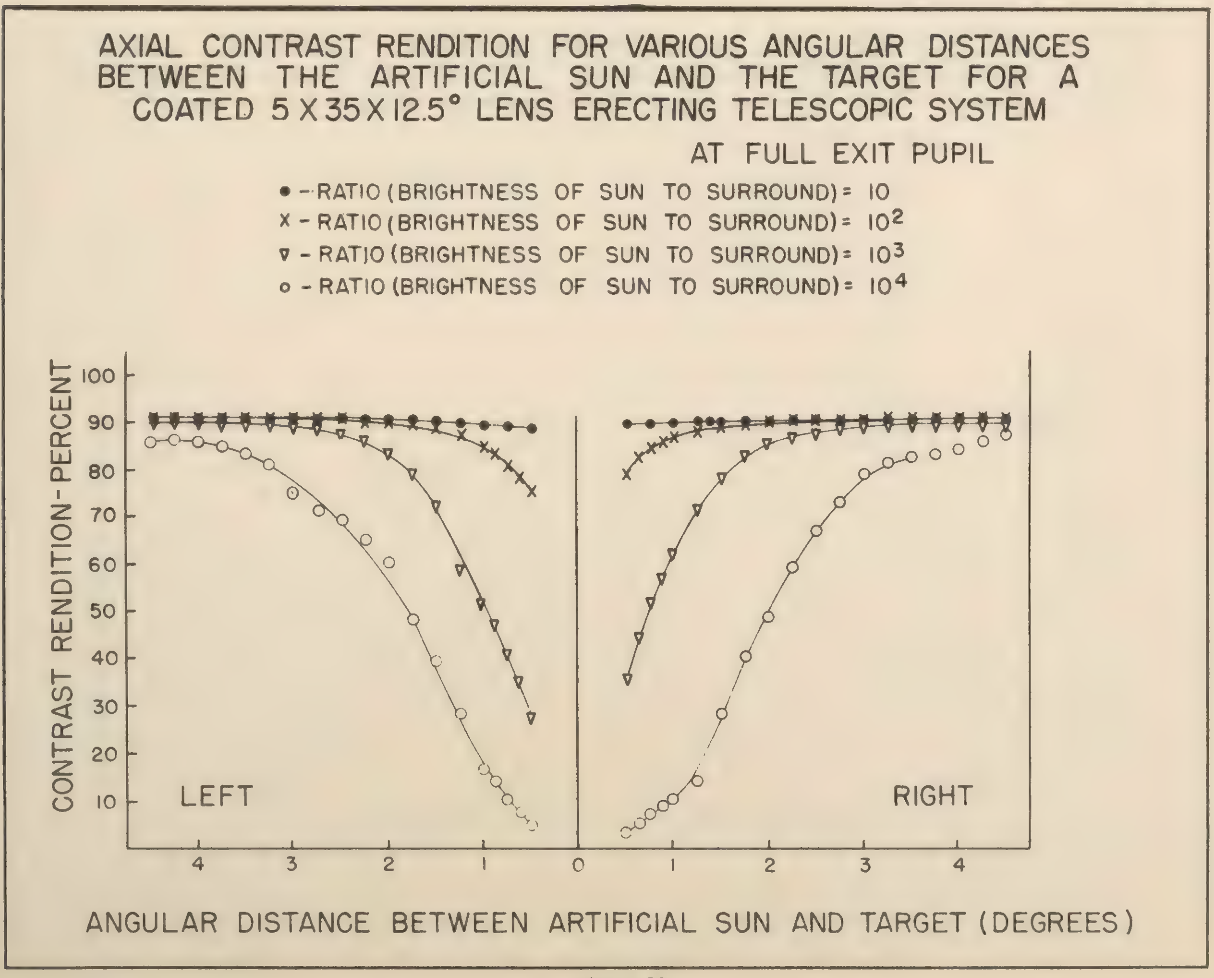

Figure 10

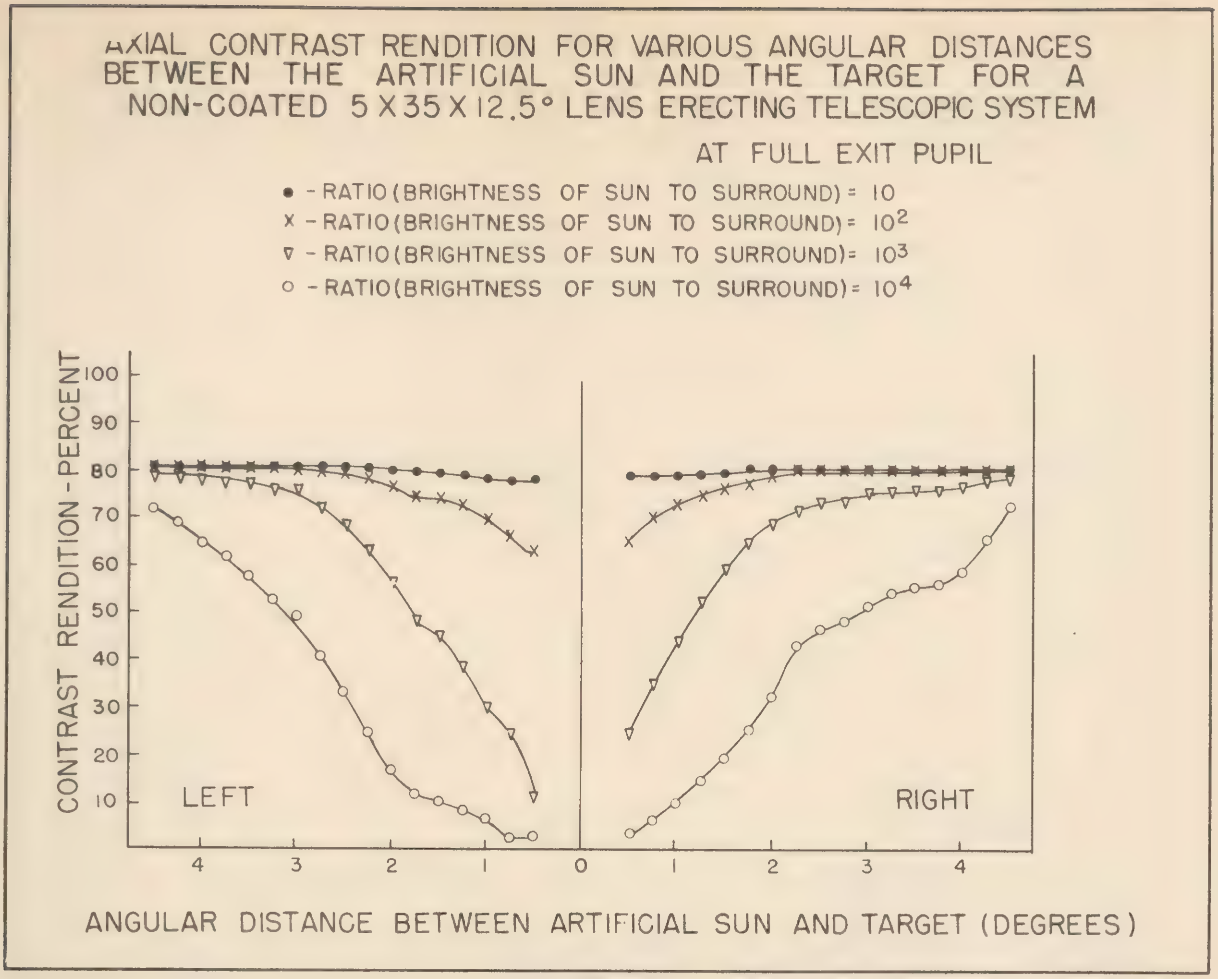

Figure 11

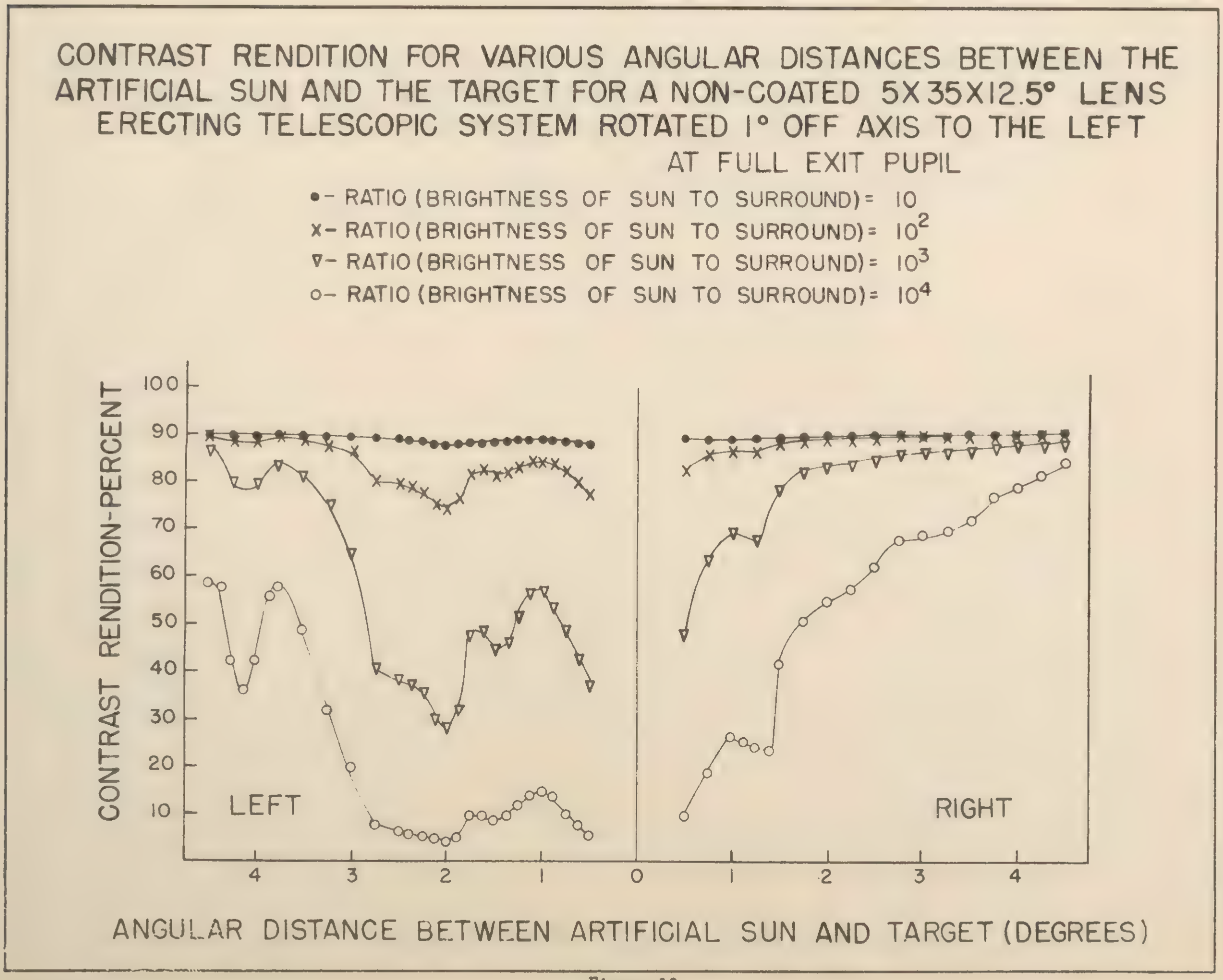

Figure 12

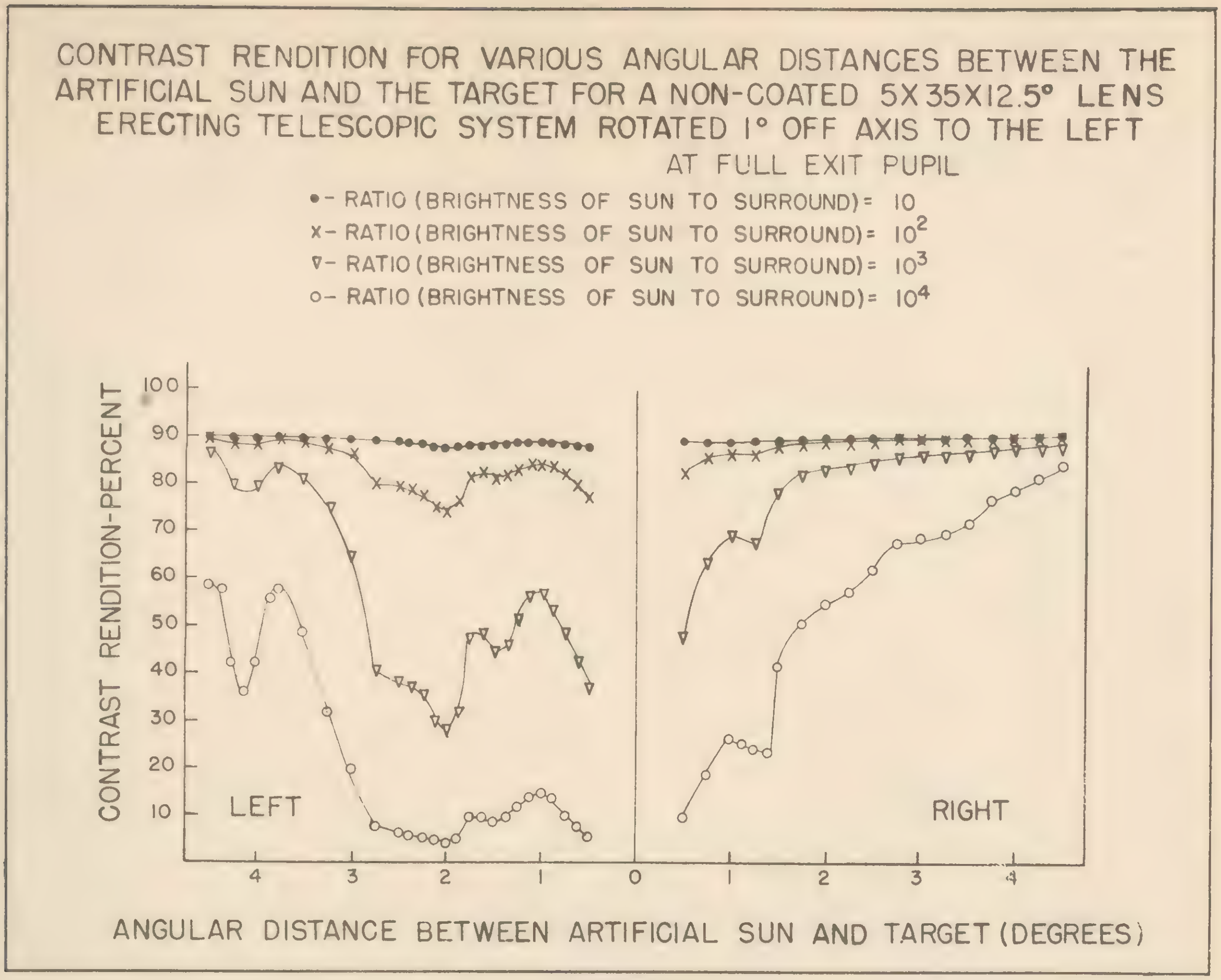

Figure 13

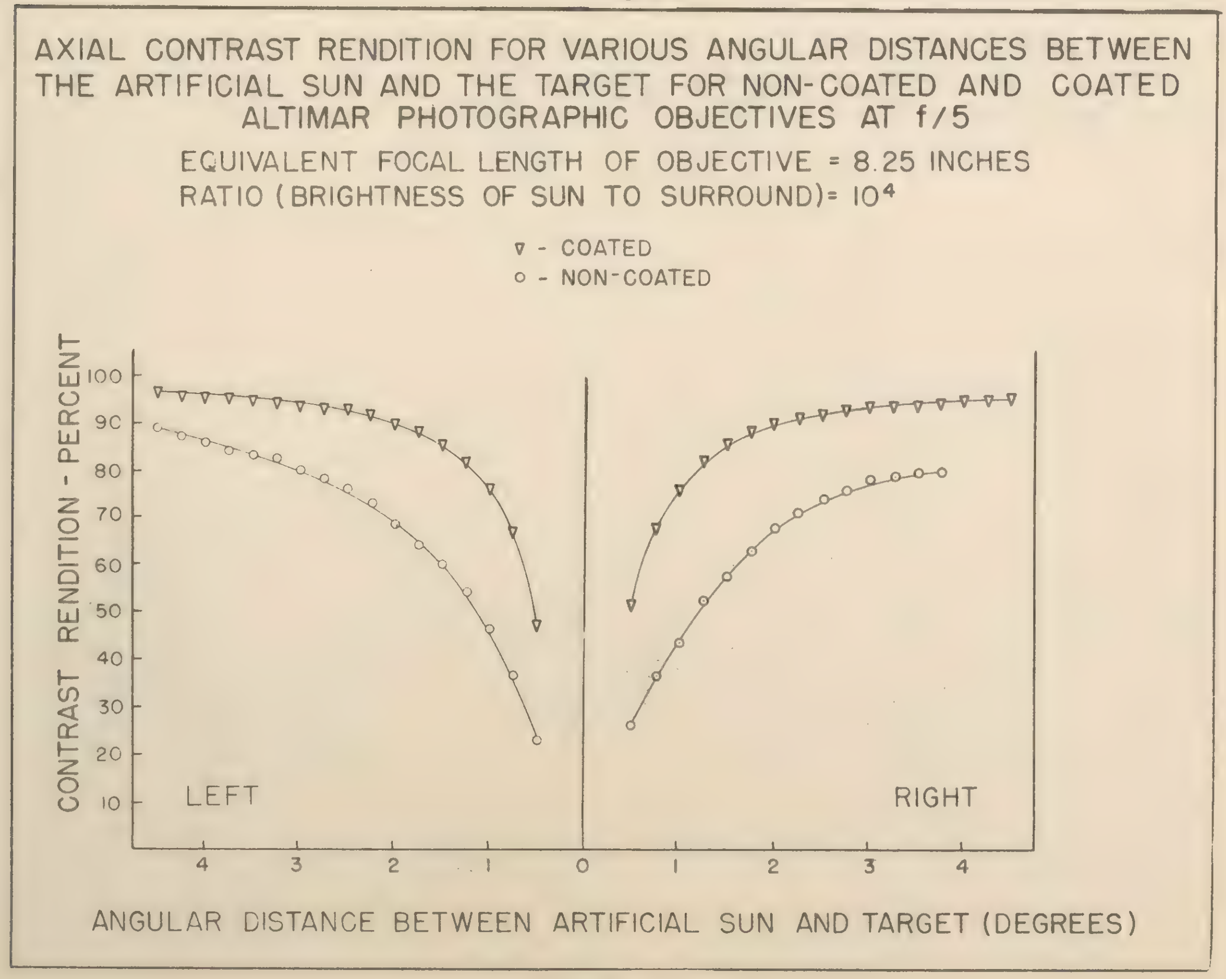

Figure 14

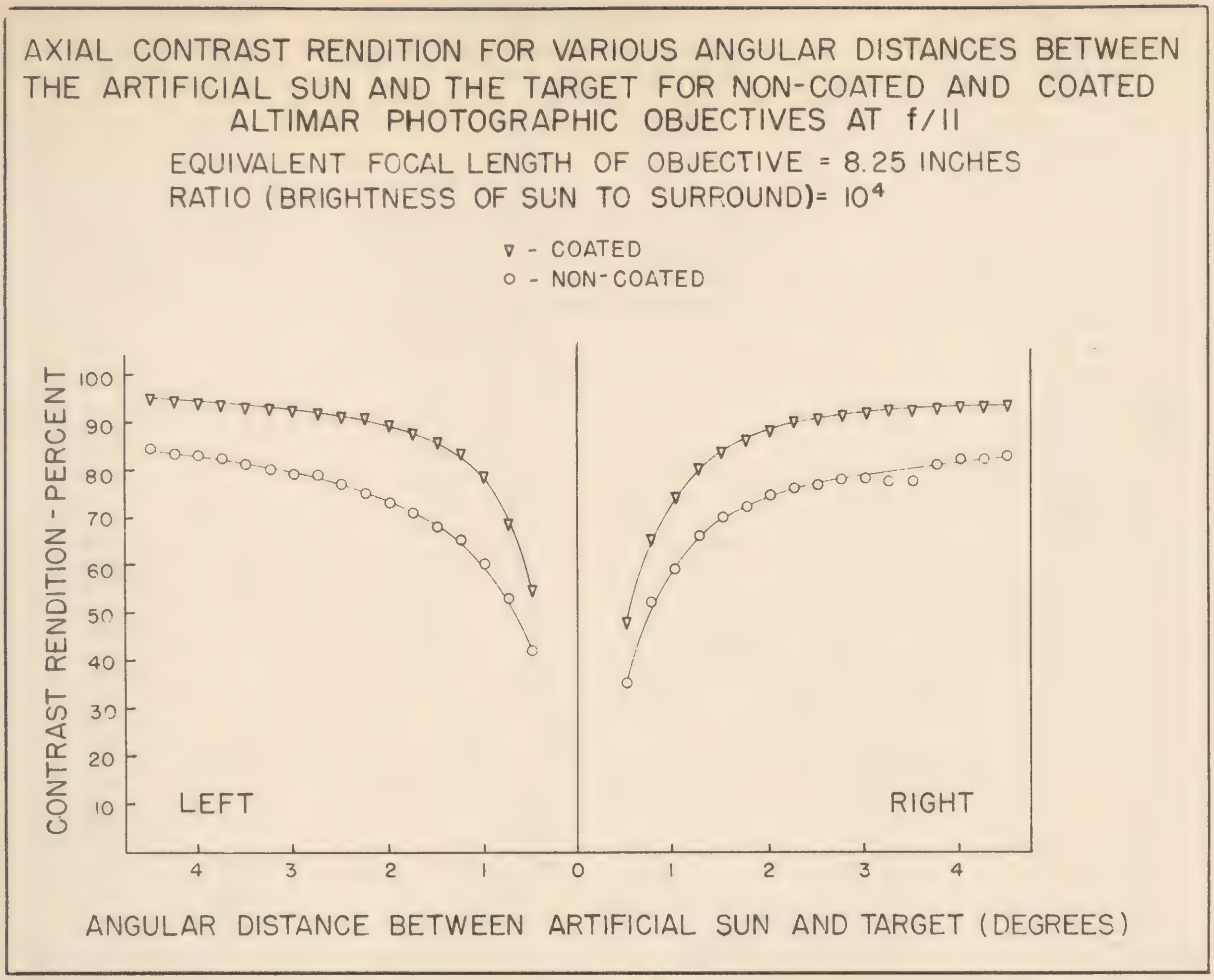

Figure 15

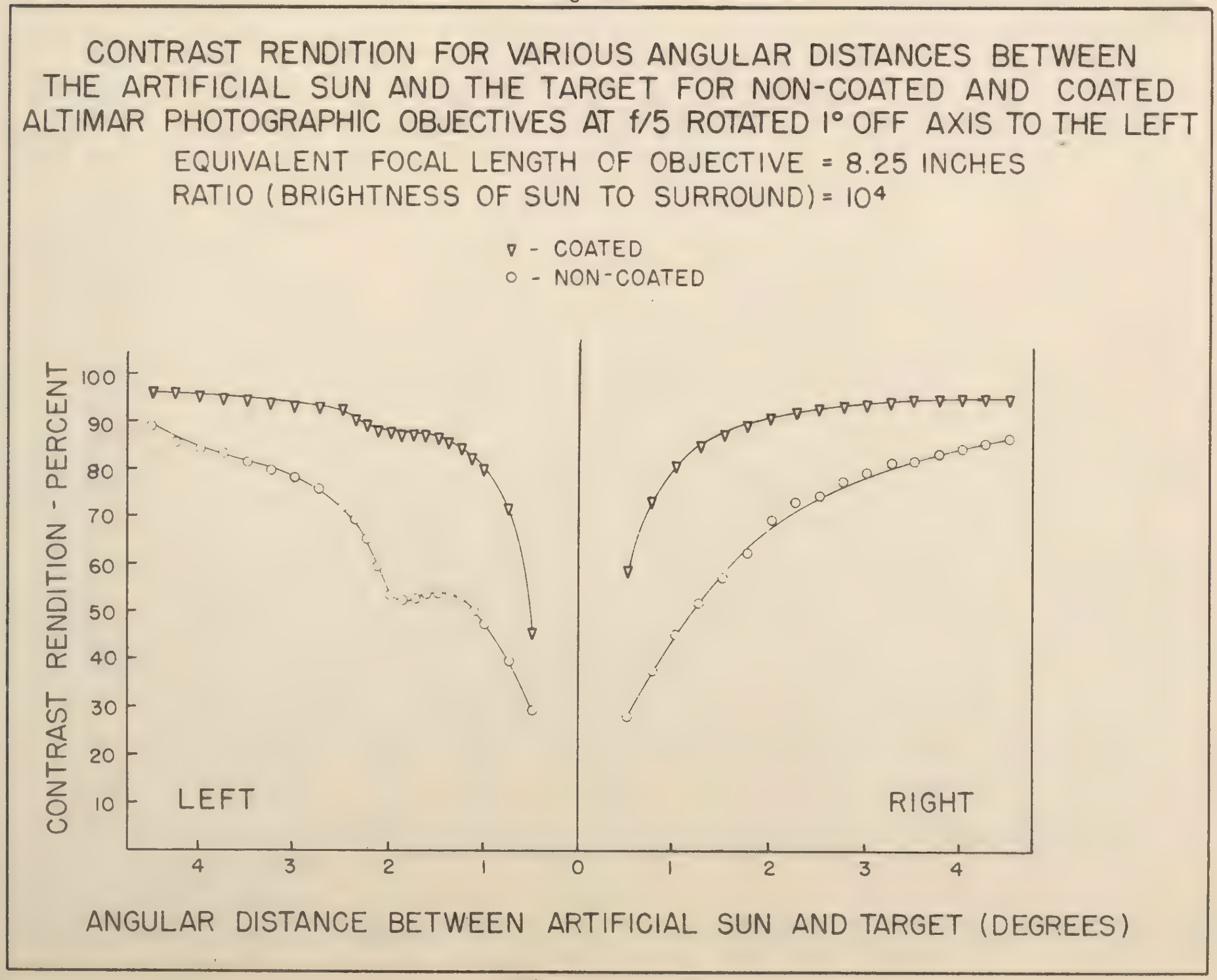

Figure 16

CONTRAST RENDITION FOR VARIOUS ANGULAR DISTANCES BETWEEN THE ARTIFICIAL SUN AND THE TARGET FOR NON-COATED AND COATED ALTIMAR PHOTOGRAPHIC OBJECTIVES AT f/11 ROTATED 1° OFF AXIS TO THE LEFT

EQUIVALENT FOCAL LENGTH OF OBJECTIVE = 8.25 INCHES
RATIO (BRIGHTNESS OF SUN TO SURROUND) = 10^4

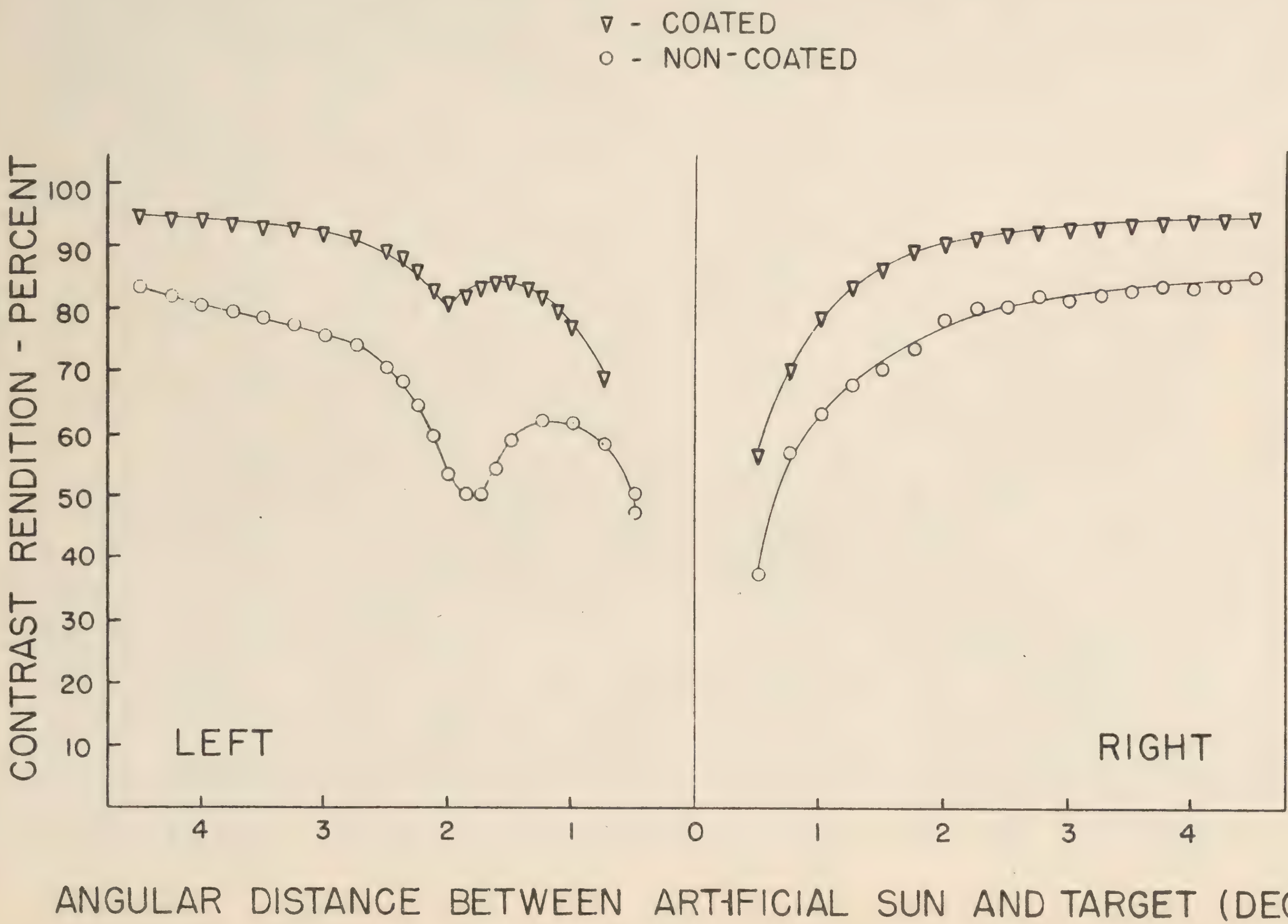

Figure 17

REORGANIZATION OF ARMY-NAVY-NRC VISION COMMITTEE

Dr. Marquis described the general set-up of the Joint Research and Development Board, of which Dr. Vannevar Bush is Chairman. He explained that the Board, consisting of five members, is implemented through a series of committees on such fields as guided missiles, atomic energy, human resources, etc. The committees are to operate in a manner most suited to the field they represent. Some committees have established a series of panels which serve as subcommittees to them.

The functions of JRDB are to examine the programs of research of the Army and Navy with the purpose of seeing that there is a strong unified, integrated, and complete program of research and development in the field of national defense. Where there is some question as to whether Army or Navy should carry out research, JRDB decides. JRDB will gradually acquire other functions as its organization is established. It will be the most broadly informed agency about research and development, since it includes both Army and Navy and secures complete information about research programs in both services. As it becomes a repository of information and organizes and utilizes information by staff secretariat, it will become a place where one can go for advice. Because JRDB has an official function, it will have to be set up with an administrative organization which makes that possible. Questions can be settled by the authority of the Secretaries of War and Navy.

Dr. Marquis raised the question of the affiliation of the Vision Committee with JRDB. The Vision Committee in the past has functioned in the manner which is somewhat different from the general pattern of the JRDB in that the Vision Committee is a large organization which has acted without authority other than persuasion, whereas the JRDB functionaries must be small groups for feasibility of administration.

The Executive Committee of the Vision Committee met on Tuesday evening to discuss the most feasible way in which the Vision Committee could fit in with JRDB organization and still maintain its unique and valuable features. It was the sense of the Executive Committee that the main Vision Committee should go on in very nearly its present form. The Vision Panel of the JRDB must have excellent liaison with the Vision Committee. To establish this, it was suggested that recommendations be made to Dr. Bush that the initial panel of JRDB be the Executive Committee of the Vision Committee. So that the main Vision Committee and the JRDB panel in vision may have most perfect liaison, the suggestion was made that the secretariat of the two organizations be identical. To facilitate this arrangement, it was suggested that the main Vision Committee be moved from Michigan to NRC Headquarters in Washington. The secretariat of the Vision Committee would be employed by JRDB as secretary for the Vision Panel, but would serve in both capacities.

Various members questioned Dr. Marquis concerning the exact functioning of proposed committee and panel. Members expressed great interest in the informality of the present committee, and felt that its informality contributed greatly to its worth. The question was raised whether if the Vision Committee did not relate itself to JRDB a "rival" organization would have to be set up. Dr. Marquis agreed that this was probably so.

Dr. Marquis agreed that there might be alternative suggestions to the one made by the Executive Committee for affiliation of the Vision Committee with JRDB. He asked the Committee for a vote of confidence for the Executive Committee to proceed with negotiations with JRDB. A unanimous vote of confidence was received.

ABSTRACTS

180. Some Considerations of High Intensity Approach Lighting.
H. J. Cory Pearson and M. S. Gilbert
Civil Aeronautics Administration, Technical Development Service, Indianapolis, Indiana
Advance Copy. Technical Development Report No. 60, March 1947, 9 pp. (0)

"This report discusses the high intensity approach lighting problem and various types and applications of lights that are being offered as solutions to the problem.

"It shows that under conditions of restricted visibility a light having a relatively moderate candlepower value can be seen from a certain maximum distance. As this candlepower is multiplied many times, the distance from which the light can be distinguished is increased very little, until a limit is reached beyond which it is impractical to increase the candlepower. There are other factors which enter into the case. The background illumination is very important, as a light that could be seen against a bright background such as prevails in daylight would be so uncomfortably glaring as to possibly blind a pilot trying to land at night with lamps of that brightness, and, conversely, light of proper brilliancy for normal night flying would be invisible under daylight conditions. These facts, known to engineers, determine the limits to which the designer may go in selecting his tools for solving the problem.

"It is obvious that there is need for brightness variation control to provide adequate brightness for visibility under diverse conditions, such as those prevailing during daytime fogs as compared with nighttime.

"Various approach lighting systems that have been, or are being tried out are discussed and criticized. The old systems had faults which the new systems attempt to eliminate by various means. There are different methods for accomplishing the same results.

"The only system which attempts to indicate to the pilot his position with respect to the glide path is the proposed CAA slope line system. This is thoroughly discussed and explained.

"With the aid of knowledge gained through exhaustive experimentation, it is believed that the engineering profession soon will find the optimum solution to the approach light problem."

181. Summary and Evaluation of the Status of Research on the Effect of the Optical Quality of Transparent Aircraft Panels on Vision.
A. Chapanis
Army Air Forces, Air Materiel Command, Engineering Division, Aero Medical Laboratory, Wright Field, Dayton, Ohio
Serial No. TSEAA-696-93, 5 August 1946, 14 pp. (0)

This report summarizes the present status of research on the effect of the optical quality of transparent aircraft panels on vision. It indicates that present conclusions will have to be reviewed constantly as aircraft design changes. Specific suggestions are made relative to further avenues of research. A 25-item bibliography is included.

182. 10 x 70 Navy Binoculars, Mark 25.
F. W. Duff
Army Ground Forces Board No. 2, Fort Knox, Kentucky

"A comparative test was conducted in conjunction with the Advanced Night Vision Class of the Armored School to determine if more extensive testing of the M25 Binocular was desirable. The night vision test course as set up by the Armored School with silhouettes of tanks, white panels, vehicles, and numerous other objects of different shapes and sizes and placed at different distances was used. Each officer compared the maximum distance he was able to observe using the 10 x 70 Binocular, M25, with that of Binoculars, M6 and M15. It was found that in almost every instance the officer was able to observe clearly approximately 10 yards further with the 10 x 70 binocular than with the standard type, but it was unanimously agreed that the 10 x 70 binocular was much harder to focus at night than the standard type and entirely too heavy for hand use."

183. The Effect of CRT Bias on Visibility of Targets on a Remote PPI.
S. B. Williams and E. King
Psychological Laboratory and Electrical Engineering Laboratory of The Johns Hopkins University
Memorandum report 166-I-6, 10 December 1946, 12 pp. (R)

"The cathode ray tube of a VD remote PPI indicator has an optimal bias level with respect to target visibility. Every experiment in which CRT bias was varied yielded a curve of visibility with a maximum lying somewhere between the lowest and highest intensity (CRT bias) settings. In all cases maximum visibility was obtained with a moderately bright, light yellow background, that is, with a comparatively low bias, and not with the dark or high bias background frequently employed by trained operators. The exact specification of this optimal level in volts or in units of illumination is not yet possible with existing measuring instruments. However, it can be fairly well defined visually. The following experiments will illustrate the difficulties of measurement and the methods employed."

184. Number of Pip-Scans and Target-Detectability on Certain High Persistence PPI Tubes.
S. B. Williams and R. M. Hanes
Psychological Laboratory and Electrical Engineering Laboratory of The John Hopkins University.
Memorandum report 166-I-7, 10 January 1947, 5 pp. (R)

"These experiments have shown that there is a small but significant enhancement of pip visibility with successive excitations of the screen. The enhancement is present on the second and third scans but does not appear in additional target-scans. The magnitude of the increase is on the order of only one or two decibels of signal voltage.

"In view of the fact that three different methods and different observers all give fairly consistent results, the possibility that the data are artifacts of method or of individual variability is almost eliminated. Furthermore, the experimental design was such as to eliminate subjective interpretation then seems to be that the effect is due to phosphor characteristics. Apparently, the second excitation comes before the first has had time to decay completely, and a summation of excitation ensues which results in an actual increase in physical brightness.

"The above conclusions are valid, of course, only for the particular combination of conditions used in the experiments. For different tube biases and for different rotation rates there would presumably be different amounts of the build-up effect. For example, one would predict that the amount of build-up effect in the phosphor would increase with bias, at least over the range covered by the linear portion of the brightness-voltage curve. Inasmuch as the eye is less sensitive to brightness differences at the low brightnesses produced by high biases, it is possible that the phosphor build-up would be insufficient to enhance visibility correspondingly."

185. Comparison of Manual and Standard Methods of Target Indication.
J. D. Reed and N. R. Bartlett
Psychological Laboratory of the Johns Hopkins University
Memorandum Report 166-I-9, 1 February 1947, 10 pp. (R)

Purpose "The present experiment compares the efficiency of two methods of target-indication on a simulated search radar: (1) the present method in which the operator estimates range and bearing with the aid of a bearing cursor and range marks, and makes a verbal report; and (2) an experimental method in which the position of each target is indicated by the use of a pointing device in the hands of the operator.

Speed and Accuracy "The manual method of indication proved equally accurate in indicating bearing, and more than twice as accurate in indicating range as the oral report of estimation. In speed of indication, the experimental method exceeded the present method more than three times. It was further shown that, using manual indication, no change in performance occurs as a result of increasing the number of targets to be indicated from 5 to 30. These findings lead to the conclusion that a system of target indication based upon pointing would give better results in terms of the performance of the operator at the search radar.

Size of PPI "An incidental result with important practical implications is that large (20 inch) PPI's, yielded no better accuracy or time score than smaller (7 inch) PPI's, using the present estimation method of indication. With manual indication, the large scopes gave no faster performance than the small ones, but did improve considerably the accuracy of the reported position."

186. Detection of New Targets on a Cathode Ray Tube (PPI Presentation) with and without an Associated Auditory Signal.
J. W. Gebhard
Systems Research Field Laboratory of the Johns Hopkins University at Jamestown, Rhode Island
Memorandum report 166-I-10, 10 February 1947, 9 pp. (R)

"(No practical use can be made of the results of this experiment at the present time. It would in fact, not be possible, for engineering reasons, to employ the experimental procedures in any operational situation. The experiment was done, however as a preliminary test of a principle which might lead to the conduct of other experiments from which practical results can be expected.)

"Two experiments were performed to determine whether the detection of a new target appearing on a radar plan position indicator (PPI) could be improved by synchronizing an auditory signal with the new blip. In the first experiment, ten faint targets were presented on a PPI, and after one sweep of observation an eleventh one appeared. In the second, ten saturated targets were presented among complex land and open sea returns, and after one sweep of observation an eleventh one appeared. The operators identified and reported the new targets upon discovery. The results of both experiments showed that detection of new targets accompanied by an auditory signal was accomplished without error, whereas targets searched for by visual means alone were found only half the time."